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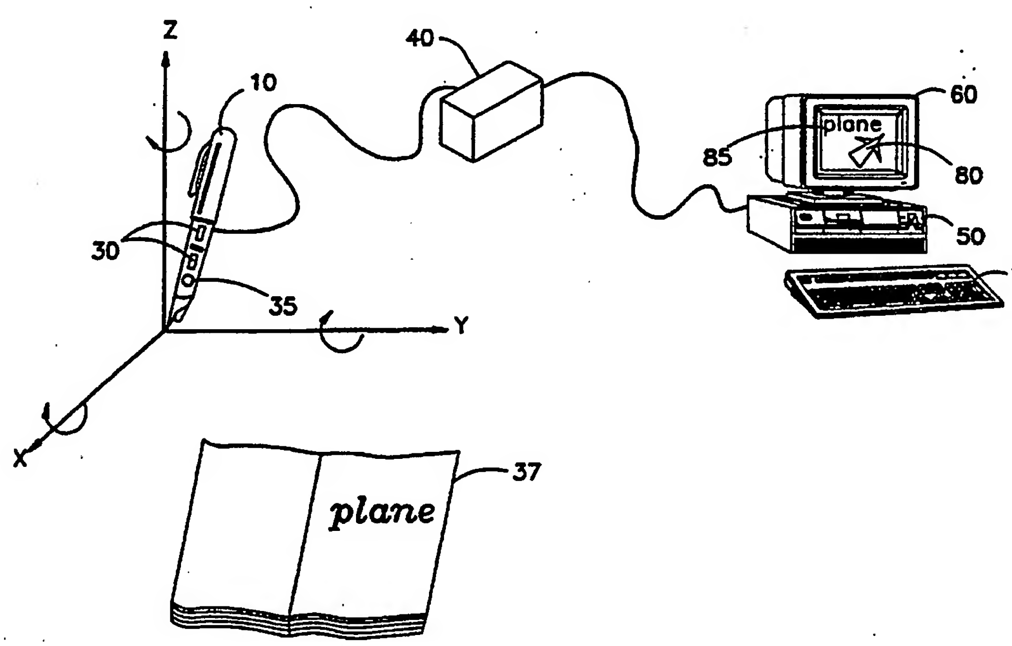

(57) Abstract

Information input apparatus (10, 40, 50, 60, 70) including body supported apparatus (10) for sensing voluntary body motions and providing an output indication thereof, a symbol output interpreter (140) operative to utilize the output indication for providing symbol outputs, and a motion output interpreter (140) operative to utilize the output indication for providing motion control outputs.

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IMPROVED INFORMATION INPUT APPARATUS

FIELD OF THE INVENTION

The present invention relates to input devices for computers generally.

BACKGROUND OF THE INVENTION

U.S. Patent 4,787,051 to Olson describes an inertial mouse system which uses three pairs of accelerometers.

U.S. Patent 4,839,836 to LaBiche et. al. describes an apparatus for providing spatial orientation data signals, using an inertial platform accelerometer cluster having a plurality of accelerometers.

U.S. Patent 5,181,181 to Glynn describes a computer apparatus input device for three-dimensional information.

SUMMARY OF THE INVENTION

The present invention seeks to provide an improved input device.

There is thus provided in accordance with a preferred embodiment of the present invention information input apparatus including body supported apparatus for sensing voluntary body motions and providing an output indication thereof, a symbol output interpreter operative to utilize the output indication for providing symbol outputs, and a motion output interpreter operative to utilize the output indication for providing motion control outputs.

Further in accordance with a preferred embodiment of the present invention, the output indication represents features of body motion including features which are characteristic of the individual.

Still further in accordance with a preferred embodiment of the present invention, a mode selector is provided which is operative to cause a selected one of the symbol output interpreter and the motion output interpreter to function.

Further in accordance with a preferred embodiment of the present invention, the body supported apparatus is a hand held device.

Still further in accordance with a preferred embodiment of the present invention, the body supported apparatus is a generally pen-shaped device.

Additionally in accordance with a preferred embodiment of the present invention, the generally pen-shaped device is operative to provide a visible writing function.

Still further in accordance with a preferred embodiment of the present invention, the information input apparatus also includes an object whose motion is

controlled by the motion control outputs.

Further in accordance with a preferred embodiment of the present invention, the object is a graphic object displayed on a display or a physical object.

Further in accordance with a preferred embodiment of the present invention, the symbol outputs represent alphanumeric symbols or a sensory quality such as an acoustic stimulus, including but not limited to music, or such as a visual stimulus, including but not limited to a color or a color image.

It is appreciated that the applicability of the present invention is very broad and is suitable for the following fields of use, inter alia: games such as video games, toys, model vehicles, robotics, simulations such as flight simulations, technical drawings and CAD.

Still further in accordance with a preferred embodiment of the present invention, the information input apparatus also includes a computer, having a location input and a symbol input, and a display operated by the computer and wherein the symbol outputs represent information to be displayed on the display and the motion outputs are supplied to the location input and are employed by the computer to govern the location of the information on the display.

Further in accordance with a preferred embodiment of the present invention, the symbol outputs include function commands.

There is also provided, in accordance with a preferred embodiment of the present invention, a method by which a manipulable device provides an output indication representing its own angular motion, the method including recording actual acceleration data from a plurality of accelerometers mounted in the manipulable device, generating predicted acceleration data on the basis of hypothetical angular motion information, comparing the predicted acceleration data to the actual accel-

eration data, computing improved hypothetical angular motion information, repeating, while the predicted acceleration data differs significantly from the actual acceleration data, the generating, comparing and computing steps, and providing an output indication of the improved hypothetical angular motion information.

Further in accordance with a preferred embodiment of the present invention, the angular motion information includes angular displacement information, angular velocity information and angular acceleration information.

Still further in accordance with a preferred embodiment of the present invention, the method includes computing linear motion information from the improved hypothetical angular motion information and from the actual acceleration data.

Additionally in accordance with a preferred embodiment of the present invention, recording includes recording from at least four accelerometers mounted in the manipulable device, wherein the accelerometers each have a center of mass and wherein the centers of mass do not lie within a single plane..

Still further in accordance with a preferred embodiment of the present invention, the method also includes receiving the output indication of the improved hypothetical angular motion information and manipulating an object in accordance therewith.

There is additionally provided, in accordance with a preferred embodiment of the present invention, an accelerometer array mounted in a manipulable device and including at least four accelerometers each having a center of mass, wherein the centers of mass do not lie within a single plane, and a manipulable device motion computer receiving input from the accelerometers and generating an output signal indicative of the motion of the manipulable device.

Further in accordance with a preferred embodiment of the present invention, the manipulable device motion computer is operative to:

record actual acceleration data from the accelerometers,

generate predicted acceleration data on the basis of hypothetical angular motion information,

compare the predicted acceleration data to the actual acceleration data,

compute improved hypothetical angular motion information,

repeat, while the predicted acceleration data differs significantly from the actual acceleration data, the generating, comparing and computing steps, and

provide an output indication of the improved hypothetical angular motion information.

Further in accordance with a preferred embodiment of the present invention, the apparatus also including an object manipulator receiving the output signal indicative of the motion of the manipulable device and manipulating an object in accordance therewith.

There is also provided, in accordance with a preferred embodiment of the present invention, an information input method including sensing voluntary body motions and providing an output indication thereof, utilizing the output indication for providing symbol outputs, and utilizing the output indication for providing motion control outputs.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated from the following detailed description, taken in conjunction with the drawings in which:

Fig. 1 is a simplified pictorial illustration of object control and handwriting recognition apparatus constructed and operative in accordance with a preferred embodiment of the present invention;

Figs. 2A and 2B are schematic drawings of preferred structures of portions of the apparatus of Fig. 1;

Fig. 3 is a simplified block diagram of the apparatus of Fig. 1;

Fig. 4 is a simplified flow chart illustrating the object control process performed by the apparatus of Fig. 1;

Fig. 5A is a simplified flow chart illustrating the process of step 440 of figure 4;

Fig. 5B comprises mathematical equations illustrating the process performed by Fig. 5A;

Fig. 6 is a simplified block diagram of the apparatus of Fig. 1;

Fig. 7A is a simplified flow chart illustrating the teaching process performed by the apparatus of Fig. 1;

Fig. 7B is a simplified flow chart illustrating the recognition process performed by the apparatus of Fig. 1; and

Figs. 8A and 8B are graphical illustrations useful in understanding a preferred method for a portion of the teaching and recognition processes performed by the apparatus of Fig. 1.

Appendix A is a computer listing of a preferred software implementation of a portion of steps 720 of Fig. 7A and 800 of Fig. 7B.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference is now made to Fig. 1 which is a simplified pictorial illustration of apparatus operative to perform motion control in synergistic combination with symbol interpretation such as handwriting recognition. A hand-held pen 10 is operative to be translated and rotated about some or all of three perpendicular axes. The term "six degrees of freedom" is used herein to designate translation along and rotation about three orthogonal axes.

Pen 10 also comprises a plurality of built-in accelerometers 25, such as model ICS 3031-2 commercially available from IC Sensors, 1701 McCarthy Blvd., Milpitas, CA 95035. Preferably, pen 10 comprises six accelerometers arranged in pairs, with each pair lying along a particular axis, with the axes being mutually orthogonal. Alternatively, the axes may not be mutually orthogonal. In any case the accelerometers need not be coplanar.

Pen 10 also comprises a plurality of amplifiers 30, associated with the plurality of accelerometers 25. Fig. 2A is a schematic drawing of a preferred embodiment of amplifier 30.

Alternatively, removable apparatus comprising a plurality of accelerometers 25 as described above, and also comprising associated amplifiers 30, as described above, may be retrofitted onto the pen 10. The removable apparatus may have the form of a cap fitting the end of the pen, a ring fitting over the pen, or any other suitable form.

In a still further alternative, the apparatus may not include a pen, but may have any other suitable hand held form. In a yet further alternative, the apparatus may be in the form of a ring fitting the user's finger, may be supported by the body of a user, or mounted thereupon in any suitable matter.

Pen 10 also comprises a switch 35, which can be used to send a signal indicating whether pen 10 is being used for handwriting recognition or as a pointing and control device. Alternatively the signal may be sent by moving pen 10 in a predefined format, or by any other appropriate means. During handwriting recognition, the user may write with pen 10 on writing surface 37.

The data from the plurality of accelerometers 25 in pen 10 is termed herein "accelerometer data". The accelerometer data is sent through a cable to a control circuit 40. Alternatively, the accelerometer data may be sent through any suitable wireless communication link, such as ultrasonic, infrared, or by any other suitable means.

Control circuit 40 amplifies the acceleration signals from pen 10 and converts them to digital form, preferably using an analog to digital converter. Fig. 2B is a schematic drawing of a preferred embodiment of an analog to digital converter suitable for the present application.

Control circuit 40 then sends acceleration data to a CPU 50. CPU 50 may be any suitable CPU such as an IBM PC compatible computer with an 80386 processor chip.

Associated with CPU 50 are a screen 60 and a keyboard 70. An object 80, such as a cursor or a graphic representation of a physical object, is displayed on screen 60. When pen 10 is used for object control, CPU 50, based on the acceleration data, moves the cursor or graphic representation 80 with six degrees of freedom, corresponding to the movement of pen 10.

A symbol 85, such as one or more characters or words, may also be displayed on screen 60. When pen 10 is used for handwriting recognition, CPU 50, based on the acceleration data, displays the symbols corresponding to what is written on writing surface 37 on screen 60.

The functionality of the apparatus of Fig. 1

will now be described. Using switch 35 the user indicates whether handwriting recognition or object control is to be performed. Depending on the user's choice, the apparatus of Fig. 1 performs the appropriate function.

The functionality of the apparatus of Fig. 1 when performing object control will now be briefly described. The user moves pen 10 in three dimensions; the motion may include six degrees of freedom. Pen 10 sends acceleration data describing the accelerations of pen 10 during the motion to control circuit 40.

Control circuit 40 amplifies and digitizes the acceleration data. The data is sent by control box 40 to CPU 50.

CPU 50 computes the translational displacement, velocity, and acceleration of pen 10 along three mutually perpendicular axes which axes need have no relation to the axes of the accelerometers. CPU 50 also computes the angular displacement (rotation), velocity and acceleration of pen 10 around the same three mutually perpendicular axes.

Based on the computed output, CPU 50 moves the cursor or the representation of an object 80 on screen 60 with translations and rotations corresponding to those of pen 10. The axes for the translation and rotation of the cursor or object correspond to the axes used to compute the translation and rotation of pen 10.

Reference is now additionally made to Fig. 3 which is a simplified block diagram of the apparatus of Fig. 1. Pen 10, when moved by the user with six degrees of freedom, transmits data describing the accelerations of pen 10 to amplification circuit 120. Amplification circuit 120 amplifies the acceleration data and transmits the amplified acceleration data to analog/digital converter 130. Analog/digital converter 130 digitizes the acceleration data and transmits the digitized data to displacement/velocity/acceleration computation apparatus

140, termed herein DVA 140.

DVA 140 computes the angular displacement, velocity, and acceleration of pen 10 around three mutually perpendicular axes which axes need have no relation to the axes of the accelerometers. DVA 140 also computes the translational displacement, velocity and acceleration of pen 10 along the same three mutually perpendicular axes.

DVA 140 transmits data describing the six degrees of freedom to screen display control 150. Based on the data, screen display control 150 updates screen 60 to show the new location and orientation of the cursor or the other object depicted on screen 60.

Reference is now additionally made to Fig. 4 which is a simplified flow chart illustrating operation of the apparatus of Fig. 1 in accordance with a preferred embodiment of the invention. The preferred method of operation of the method of Fig. 4 includes the following steps:

STEP 410: Read accelerometer data. Data from each of the plurality of accelerometers 25 is sampled, preferably at a rate of one thousand data points per second.

STEP 412: Check whether session is at the beginning. At the beginning of a session, STEP 420, described below, is required.

STEP 415: Check whether pen is in motion. The accelerometer data is analyzed to determine whether pen 10 is in motion.

Preferably, pen 10 is considered to be not in motion whenever all of the acceleration signals indicate that the only sensed accelerations are due to gravity. Signals are chosen from one member of each of three pairs of accelerometers, each pair arranged along a different axis.

Let the vector $U=(U_1,U_2,U_3)$ denote the signals

of the three accelerometers. Let the matrix $A=(K_1,K_2,K_3)$ denote the sensitivities of each of the three accelerometers.

The sensitivities of the accelerometers correct for any deviations of the axes of each pair of accelerometers as they are actually mounted in pen 10 from the common axis on which they are supposed to be situated; this component of the sensitivity is called static sensitivity. The sensitivities also correct for deviations between the axes of the global orthogonal coordinate system and the axes of the pairs of accelerometers; this component of the sensitivity is called dynamic sensitivity. In actual practice, both static sensitivity and dynamic sensitivity may make important contributions to sensitivity.

The static sensitivity is computed as part of step 420, described in detail below. The dynamic sensitivity is computed as part of step 455, described in detail below.

Let ϵ denote a small positive constant; for example, .005g where g denotes the acceleration of gravity at the earth's surface. Then the pen is considered not to be in motion whenever $1-\epsilon < |A^{-1}U| < 1+\epsilon$.

STEP 420: Compute initial conditions. The initial conditions may comprise the initial Euler angles between the global coordinate system and the axes of the pairs of accelerometers. These Euler angles are now determined.

Assuming that, at the initial condition, either at the beginning of the session or when the pen is not in motion, the only accelerations measured are due to gravity, the static sensitivity can be computed from the accelerometer data while the pen is at rest in three known orientations. Alternatively, the static sensitivity can be computed once as a property of the pen and stored for future use.

STEP 430: Compute the differential signal from each pair of accelerometers. The signals from each member of each pair of accelerometers are subtracted to form a differential signal for each pair of accelerometers.

STEP 440: Compute rotational parameters. The rotational parameters define parameters of the motion about the three axes of the global coordinate system. The rotational parameters comprise the three Euler angles; the three angular velocities; and the three angular accelerations.

The rotational parameters are computed in parallel using an iterative feedback loop. In each iteration of the loop, an estimated differential acceleration is computed from the current rotational parameters. If the difference between the estimated differential acceleration and the actual differential acceleration signal is less than a predetermined amount, iteration is terminated.

Otherwise, new values of the parameters are estimated in each iteration from the previous values and the difference between the estimated differential acceleration and the actual differential acceleration data. The method of this step is described more fully below with reference to Fig. 5.

STEP 450: Compute translation acceleration. The angular orientation and the angular acceleration are known from step 440. From the angular orientation and the sensitivity vector the acceleration due to gravity is computed.

Given the angular acceleration and the acceleration due to gravity as well as the sensitivity vector, the translational acceleration is computed. The computation is according to the formula $a_t=K^{-1}u-a_g-a_r$ where a_t is the translational acceleration; K is the sensitivity vector; u is the signal of one accelerometer; a_g is the

component of the acceleration of gravity sensed by the one accelerometer; and a_r is the angular acceleration.

STEP 455: Update dynamic sensitivity. As explained above, the dynamic sensitivity represents deviations between the axes of the global orthogonal coördinate system and the axes of the pairs of accelerometers. Since the angular orientation of pen 10 may have changed, the dynamic sensitivity may also have changed.

Given the change in the angular orientation of pen 10, the new dynamic sensitivity may be computed from the new angular orientation and the old matrix of dynamic sensitivity.

STEP 460: Compute translational velocity and displacement. The translational velocity is computed by integrating the translational acceleration with respect to time. The displacement is computed by integrating the translational velocity with respect to time.

STEP 470: Move screen object. Based on the output of previous steps which comprises translational acceleration, velocity and displacement as well as angular acceleration, velocity and orientation, the screen object is moved. The moving of the screen object may be according to any appropriate transformation of the motions of pen 10.

Reference is now additionally made to Fig. 5A which is a simplified flowchart illustrating to operation of step 440 of Fig. 4. Fig. 5A includes the following steps:

STEP 480: Set initial parameters. The rotational parameters comprise the three Euler angles; the three angular velocities; and the three angular accelerations. The initial value for the Euler angles is computed based on the previously known value of the parameters, assuming that the acceleration has remained constant.

STEP 482: Compute differential acceleration from model. First the position of an accelerometer in

the coordinate system of the pen is defined by vector r and the rotation of the pen in the global coordinate system is defined by a rotation matrix A(phi). For example, A(phi) may be an appropriate rotation matrix as presented in sections 14.10-5 through 14.10-7, pages 475-480 of Mathematical Handbook for Scientists and Engineers by Korn and Korn, 2nd Edition, published by McGraw-Hill in 1968. Here phi is a vector of Euler angles: phi=$(\alpha,\beta,\Gamma)^T$. Then the position of the accelerometer in the global coordinate system R is defined by R=Ar.

Reference is hereby additionally made to Fig. 5B, which contains equations useful for understanding the steps of Fig. 5A. Equation 490 illustrates the computation of the acceleration of the accelerometer in the global coordinate system.

As the Euler angles of the accelerometer change, the sensitivity vector K also changes. The change in the sensitivity vector K may be computed by using equation 492 of Fig. 5B.

Given the acceleration of the accelerometer and the new sensitivity vector, the estimated value for the differential signal of the accelerometer, u_{est} may be computed by using equation 494 of Fig. 5B.

The remainder of the parameters may be computed with an appropriate model. Preferably, a model which allows the use of only the parameters specified above, rather than a larger number of parameters, is used. For example, equation 496 of Fig. 5B represents an appropriate model for computing the remainder of the parameters.

STEP 484: Is the difference between the computed and the current value less than a predetermined amount? If the difference is less than this amount, the estimated parameters are taken to be correct and iteration is terminated, with the computed parameters being reported.

An appropriate value for the predetermined

amount may vary depending on, for example, the maximum number of desired iterations. One possible appropriate value would be .0003 g, where g represents the acceleration of gravity at the earth's surface.

STEP 486: Compute changes in estimated angles according to the gradient method. New estimated angles are computed by adding a change to the old estimated angles; the change is computed according to the gradient method. The gradient method is explained more fully in section 20.3-3 of Mathematical Handbook for Scientists and Engineers by Korn and Korn, referred to above.

STEP 488: Compute new parameters. New values for the remaining parameters are computed. Iteration then continues with step 482.

The functionality of the apparatus of Fig. 1 when performing handwriting recognition will now be briefly described. Pen 10 sends acceleration data through control circuit 40 to CPU 50. Teaching and recognition then occur based on the data from pen 10.

Reference is now additionally made to Fig. 6 which is a simplified block diagram of the apparatus of Fig. 1 when used for handwriting recognition. The apparatus of Fig. 6 receives input from pen 10.

Pen 10, when moved by the user of the handwriting recognition apparatus, transmits data describing the accelerations of pen 10 over time to acceleration teaching control 630 and/or acceleration handwriting recognition control 650.

The data from pen 10 may be transmitted to acceleration teaching control 630. Transmission to acceleration teaching control 630 typically occurs for each person who is to use the system for handwriting recognition for the first time. Transmission to acceleration teaching control 630 also preferebly occurs when recognition errors are detected; use of acceleration teaching control 630 when recognition errors are detected is

termed herein adaptive teaching.

Acceleration teaching control 630 operates on the data received, which data represents hand movements by the user when writing a symbol, together with manually-provided identification of the symbol codes that are associated with the data. Acceleration teaching control 630 then updates database 640, a per-person per-symbol acceleration database. Database 640 comprises prototypes of accelerations for each symbol, comprising data specific to each person for each symbol.

Alternatively, the data from pen 10 may be transmitted to acceleration handwriting recognition control 650. Acceleration handwriting recognition control 650 operates on the data received from pen 10 to recognize the symbol represented by the movement of pen 10.

The output of acceleration handwriting recognition control 650 comprises a list of symbol codes and their respective probabilities. An acceleration handwriting recognition post-processing circuit 660, chooses the correct symbol code based on the list of symbol codes and probabilities, and on post-processing information which preferably comprises a database of previous confusions and a dictionary. The output of acceleration handwriting recognition post-processing circuit 660 is a list of symbol codes and/or words sorted by likelihood.

Reference is now additionally made to Figs. 7A and 7B which are simplified flow charts illustrating operation of the apparatus of Fig. 7 in accordance with a preferred embodiment of the invention, when performing handwriting recognition. Fig. 7A illustrates the teaching process and Fig. 7B illustrates the recognition process. The steps in Fig. 7A include the following:

STEP 710: Read accelerometer data. The accelerometer data comprises data points representing sampling of the acceleration measured by accelerometers 25.

Preferably, the sampling rate is approximately 1600 data points per second, averaged over 8 points, producing an output of approximately 200 data points per second.

STEP 712: Identify pen-surface contact termination. The data from step 710 does not include the surface contact status of pen 10. The surface contact status of pen 10 may be derived from the acceleration data as follows:

The acceleration data is filtered to remove components other than noise. For example, the acceleration data may be filtered by a Butterworth digital filter described in Digital Filter Design by T.W. Parks and C.S Burrus, John Wiley & Sons, 1987, chapter 7, section 7.3.3, using the 4th order lowpass digital filter with a cut-off frequency of 0.7 to 0.9.

The filtered acceleration data is then integrated over time. The slope of the integrated filtered acceleration data is then analyzed to determine the point at which the slope exceeds a threshold value. The point at which the slope exceeds the threshold value is taken to be the first point with status "pen down". The point at which the slope falls below a threshold value is taken to be the first point with status "pen up"; the threshold value may or may not be the same as the previously described threshold value.

The threshold values described above may be determined in advance for the particular type of pen and writing surface, may be determined by a learning process for the particular person, or may be determined by other means.

STEP 715: Identify individual symbols and words. The data from the previous step is divided into data representing individual symbols. The status which comprises the status of "pen up" is termed herein "pen not down". Preferably, the number of consecutive data points with status of "pen not down", which data points

represent a particular duration of the status "pen not down" is taken to indicate the end of a symbol or of a word.

Typically, the duration of status "pen not down" within a range from 200 milliseconds to 400 milliseconds is taken to indicate the end of a symbol. Duration of the status "pen not down" in the range from 800 milliseconds to 1200 milliseconds is typically taken to indicate the end of a word.

Alternatively, the end of a symbol or of a word may be indicated by data points which represent pen movements that are not part of a symbol, or by other means. Output data from step 715 comprises symbol end and word end data.

STEP 720: Normalize accelerometer data. The accelerometer data is normalized in time or by other means. Appendix A is a computer listing in the C programing language comprising routines that are a preferred implementation of step 720. The routines comprise the following routines in section II, "pre-preprocessing": normal; together with various definitions used by routine normal.

STEP 730: Filter accelerometer data. The normalized accelerometer data received from the previous step is filtered in order to remove noise. The filtering may be accomplished by iterative smoothing of adjacent points until the total change in the signal due to a smoothing operation is less than the desired accuracy of the data, or by other suitable means.

STEP 740: Parameterize accelerometer data. The data is parameterized according to criteria which are chosen to represent each symbol. If the accelerometers are not mutually orthogonal, the acceleration data may be converted into equivalent data in a mutually orthogonal coordinate system as follows:

Let the non-orthogonal signals be denoted by

the vector $u=(u_1,u_2,u_3)^T$ and the orthogonal signals be denoted by the vector $u'=(u'_1,u'_2,u'_3)^T$. Then $u'=A_0A^{-1}u$ where A is a vector of static sensitivity vectors $A=(A_1,A_2,A_3)$ of the three accelerometers. The static sensitivity vector is computed from the outputs of the accelerometers during a defined orientation without movement. A_0 is a diagonalized matrix of sensitivity of the orthogonal coordinate system comprising the norms of A_1, A_2, and A_3.

The parameters preferably comprise the following:

number of points before normalization;

normalized signal of pen status;

normalized signal of Z acceleration;

sine of the angle α' which angle is defined as the angle between the vector associated with the current data point $(AccX_i,AccY_i,AccZ_i)$ and the AccXAccY plane as shown in Fig. 8A;

cosine of the angle α';

sine of the angle β' which angle is defined as the angle between the vector that connects the point before the previous data point $(AccX_{i-2},AccY_{i-2},AccZ_{i-2})$ and the current point $(AccX_i,AccY_i,AccZ_i)$, and the vector that connects the current point with the point after the subsequent point $(AccX_{i+2},AccY_{i+2},AccZ_{i+2})$ in space (AccX,AccY,AccZ) as shown in Fig. 8B;

and cosine of the angle β'.

STEP 750: Generalize parameters. The parameters of the symbol being learned represent a specific instance of the symbol. The symbol prototype stored by the system is to represent the general characteristics of the symbol as drawn by that person. Therefore, the parameters of the symbol being learned are generalized by some suitable means, such as by computation of the average of the value of each parameter from previous instances of the symbol along with the value of each param-

eter from the current instance of the symbol.

STEP 760: Update per-person per-symbol acceleration prototype database. The newly computed parameters from the previous step are stored in the per-person per-symbol acceleration prototype database.

The steps in Fig. 7B include steps which have already been described above with reference to Fig. 7A. The remainder of the steps in Fig. 7B include the following:

STEP 800: For each prototype in the per-person per-symbol acceleration prototype database, build a measure of comparison between the sample and the prototype, combined over parameters in the prototype. In accordance with a preferred embodiment of the present invention, all parameters are combined together to produce the measure of comparison. Appendix A is a computer listing in the C programing language comprising routines that are a preferred implementation of step 800. The routines comprise the following, which are found in section V, "symbols recognition": make_corr; correl_hem; obj_funct; together with various definitions used by the routines.

STEP 810: Create a list of probable symbols sorted by likelihood. Based on the measure or measures of comparison generated in step 800, a single list of probable symbols sorted by likelihood is generated.

STEP 820: Choose the correct symbols and the correct word based on the list, the database of previous confusions and a dictionary. The symbols with greatest likelihood are the candidates from which the correct symbol is chosen.

The database of previous confusions provides information that allows the correction of the choice of the correct symbol based on previous incorrect identifications. The database of previous confusions comprises, for each symbol, a list of other symbols which have been

confused with the first symbol; for example, that the symbol "f" has often been confused with the symbol "b". When such an entry is found comprising previous confusions for a symbol in the list, the symbol or symbols that have previously been confused with the symbol in the list are added to the list. In accordance with the previous example, if the symbol "f" is found in the list, then the symbol "b" is added to the list.

An indication of the end of each word has been passed as output since step 715, described above. Based on the indication, the most likely word, comprising the most likely identifications for each symbol in the list, is identified.

The most likely word is checked against the dictionary. Preferably, the dictionary comprises both a general dictionary used for all users of the system and a personal dictionary for each user of the system. If an entry exists in the dictionary for the most likely word, the word is chosen as the correct identification.

If the most likely word is not found in the dictionary, all possible word combinations in the list are formed and each is checked against the dictionary. Among all such words which are found in the dictionary, the word with the highest likelihood is then chosen as the correct identification.

If none of the words is found in the diction-ary, the most likely word is chosen as the correct iden-tification.

STEP 830: Check to see if a correction has been entered. During the process of recognition, the user of the system is preferably provided with a visual indication of each symbol recognized.

After the end of a word is detected, the user of the system preferably is provided with a visual indi-cation of the word recognized. The user may indicate manually that a given word was incorrectly recognized and

may input a correction.

STEP 840: Update database of previous confusions. Based on a manual correction entered in step 830 or an automatic correction based on the dictionary, the database of previous confusions is updated. Based on a manual correction, the personal dictionary is also updated if the corrected word is not found in the dictionary.

Preferred methods and apparatus for handwriting recognition are described in the following applications, the disclosure of which is hereby incorporated by reference: PCT/US92/08703; Israel 104575; PCT application filed 31 January 1994 in the US Receiving Office by Ehud Baron and Edward A. Wolfe.

It is appreciated that the particular embodiment described in Appendix A is intended only to provide an extremely detailed disclosure of the present invention and is not intended to be limiting.

It is appreciated that various features of the invention which are, for clarity, described in the contexts of separate embodiments may also be provided in combination in a single embodiment. Conversely, various features of the invention which are, for brevity, described in the context of a single embodiment may also be provided separately or in any suitable subcombination.

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention is defined only by the claims that follow:

APPENDIX A

Recognition according a combination of signals.

Definitions and data structures

Board.H file

```
/* Function init_datatr ( portbase ) sets communication with data
   translation board via port portbase. It returns :
                    0 - communication was established ;
                   -1 - error on board (board is not exist). */
//int init_datatr ( int ) ;

int newcomp ( void ) ;

int read_ch ( int channel , int gain ) ;

//int read_point ( struct point * , int ) ;

/*int read_block ( struct point * , int max_numb_point ,
                   int timeout_for_begin , int timeout_for_end ,
                   int key_mouse_stop ) ; */

//int read_symbol ( struct point * , int , int ) ;

int mshit ( void ) ;

void close_datatr ( void ) ;

#define PORT_BASE    0x210

#define KEY_STOP       0x1
#define MOUSE_STOP     0x2
#define KEY_MOUSE_STOP 0x3

#define PEN_WAIT       0x1
#define PEN_NOWAIT     0x0
```

Data.H file

```
struct point_pen
{
   unsigned ax ;
   unsigned ay ;
   unsigned az ;
   unsigned pn ;
} ;
struct point_tablet
{
   int x ;
   int y ;
   int p ;
} ;
#define SYNCROBIT    0x80
```

```
Datar.H file
#define PORT_BASE    0x210
#define CSR          0x0
#define GAIN         0x1
#define DAC0_LOW     0x2
#define DAC0_HIGH    0x3
#define DAC1_LOW     0x4
#define DAC1_HIGH    0x5

#define CHANNEL_AX    0x4
#define CHANNEL_AY    0x5
#define CHANNEL_AZ    0x6
#define CHANNEL_PN    0x7
#define STATUS        0xe
#define CHANNEL_EMPTY 0x0

#define IDREGISTER    0xf

#define GAIN_1     0x00
#define GAIN_2     0x40
#define GAIN_4     0x80
#define GAIN_8     0xc0

#define IER      0x21
#define IIR      0x20

#define IRQ0      0x08
#define IRQ1      0x09
#define IRQ2      0x0a
#define IRQ3      0x0b
#define IRQ4      0x0c
#define IRQ5      0x0d
#define IRQ6      0x0e
#define IRQ7      0x0f

/*struct point {
  unsigned ax ;
  unsigned ay ;
  unsigned az ;
  unsigned pn ;
} ;*/
#define MINUS_PEN    1700
/*#define PEN_UP     0x2
#define PEN_DOWN     0x4
#define PEN_THRSLD   200
#define EMPTY                0    */

#define BUFSIZE     0x80


#define TIME_COUNT   3000
#include <dos.h>
```

Ser.H file

```
/*-------------------------------------------------------------------*
  FILENAME:              SERIAL.H

            Some definitions used by SER.C

 *-------------------------------------------------------------------*/

#define COM1          1
#define COM2          2
#define COM1BASE       0x3F8  /* Base port address for COM1 */
#define COM2BASE       0x2F8  /* Base port address for COM2 */

/*
   The 8250 UART has 10 registers accessible through 7 port addresses.
   Here are their addresses relative to COM1BASE and COM2BASE. Note
   that the baud rate registers, (DLL) and (DLH) are active only when
   the Divisor-Latch Access-Bit (DLAB) is on. The (DLAB) is bit 7 of
   the (LCR).

        o TXR Output data to the serial port.
        o RXR Input data from the serial port.
        o LCR Initialize the serial port.
        o IER Controls interrupt generation.
        o IIR Identifies interrupts.
        o MCR Send contorl signals to the modem.
        o LSR Monitor the status of the serial port.
        o MSR Receive status of the modem.
        o DLL Low byte of baud rate divisor.
        o DHH High byte of baud rate divisor.
*/
#define TXR          0     /* Transmit register (WRITE) */
#define RXR          0     /* Receive register  (READ)  */
#define IER          1     /* Interrupt Enable          */
#define IIR          2     /* Interrupt ID              */
#define LCR          3     /* Line control              */
#define MCR          4     /* Modem control             */
#define LSR          5     /* Line Status               */
#define MSR          6     /* Modem Status              */
#define DLL          0     /* Divisor Latch Low         */
#define DLH          1     /* Divisor latch High        */


/*-------------------------------------------------------------------*
  Bit values held in the Line Control Register (LCR).
        bit            meaning
        ---            -------
        0-1            00=5 bits, 01=6 bits, 10=7 bits, 11=8 bits.
        2              Stop bits.
        3              0=parity off, 1=parity on.
        4              0=parity odd, 1=parity even.
        5              Sticky parity.
        6              Set break.
        7              Toggle port addresses.
 *-------------------------------------------------------------------*/
#define NO_PARITY      0x00
#define EVEN_PARITY    0x18
#define ODD_PARITY     0x08
```

```
/*--------------------------------------------------------------*
  Bit values held in the Line Status Register (LSR).
        bit             meaning
        ---             -------
        0               Data ready.
        1               Overrun error - Data register overwritten.
        2               Parity error - bad transmission.
        3               Framing error - No stop bit was found.
        4               Break detect - End to transmission requested.
        5               Transmitter holding register is empty.
        6               Transmitter shift register is empty.
        7            Time out - off line.
 *--------------------------------------------------------------*/
#define RCVRDY       0x01
#define OVRERR       0x02
#define PRTYERR      0x04
#define FRMERR       0x08
#define BRKERR       0x10
#define XMTRDY       0x20
#define XMTRSR       0x40
#define TIMEOUT            0x80

/*--------------------------------------------------------------*
  Bit values held in the Modem Output Control Register (MCR).
        bit      meaning
        ---             -------
        0               Data Terminal Ready. Computer ready to go.
        1               Request To Send. Computer wants to send data.
        2               auxillary output #1.
        3               auxillary output #2.(Note: This bit must be
                        set to allow the communications card to send
                        interrupts to the system)
        4               UART ouput looped back as input.
        5-7             not used.
 *--------------------------------------------------------------*/
#define DTR          0x01
#define RTS          0x02
#define MC_INT             0x08


/*--------------------------------------------------------------*
  Bit values held in the Modem Input Status Register (MSR).
        bit             meaning
        ---             -------
        0               delta Clear To Send.
        1               delta Data Set Ready.
        2               delta Ring Indicator.
        3               delta Data Carrier Detect.
        4               Clear To Send.
        5               Data Set Ready.
        6               Ring Indicator.
        7               Data Carrier Detect.
 *--------------------------------------------------------------*/
#define CTS          0x10
#define DSR          0x20
```

```
/*---------------------------------------------------------------*
  Bit values held in the Interrupt Enable Register (IER).
        bit             meaning
        ---             -------
        0               Interrupt when data received.
        1               Interrupt when transmitter holding reg. empty.
        2               Interrupt when data reception error.
        3               Interrupt when change in modem status register.
        4-7             Not used.
*---------------------------------------------------------------*/
#define RX_INT       0x01


/*---------------------------------------------------------------*
  Bit values held in the Interrupt Identification Register (IIR).
        bit             meaning
        ---             -------
        0               Interrupt pending
        1-2          Interrupt ID code
                        00=Change in modem status register,
                        01=Transmitter holding register empty,
                        10=Data received,
                        11=reception error, or break encountered.
        3-7             Not used.
*---------------------------------------------------------------*/
#define RX_ID        0x04
#define RX_MASK        0x07


/*
   These are the port addresses of the 8259 Programmable Interrupt
   Controller (PIC).
*/
#define IMR          0x21  /* Interrupt Mask Register port */
#define ICR          0x20  /* Interrupt Control Port      */


/*
   An end of interrupt needs to be sent to the Control Port of
   the 8259 when a hardware interrupt ends.
*/
#define EOI          0x20  /* End Of Interrupt */


/*
   The (IMR) tells the (PIC) to service an interrupt only if it
   is not masked (FALSE).
*/
#define IRQ3         0xF7  /* COM2 */
#define IRQ4         0xEF  /* COM1 */


/*
   The (IMR) tells the (PIC) to service an interrupt only if it
   is not masked (FALSE).
*/
#define IRQ3         0xF7  /* COM2 */
#define IRQ4         0xEF  /* COM1 */
```

```
int flag;
int  SetSerial();
int  SetOthers(int Parity, int Bits, int StopBit);
int  SetSpeed(int Speed);
int  SetPort(int Port);
void init_serial(void);
void comm_off(void);

void setallport(int Port, int Speed, int Parity, int Bits, int StopBit);
int  putchport (char);
void putstrport(char *);
int  getchport(void);
void offport();
```

Serconst.H file

```
/*-----------------------------------------------------------------*
  FILENAME:                 SERCONST.H

                   Some definitions used by SER.C

 *-----------------------------------------------------------------*/


/*
   The 8250 UART has 10 registers accessible through 7 port addresses.
   Here are their addresses relative to COM1BASE and COM2BASE. Note
   that the baud rate registers, (DLL) and (DLH) are active only when
   the Divisor-Latch Access-Bit (DLAB) is on. The (DLAB) is bit 7 of
   the (LCR).

        o TXR Output data to the serial port.
        o RXR Input data from the serial port.
        o LCR Initialize the serial port.
        o IER Controls interrupt generation.
        o IIR Identifies interrupts.
        o MCR Send contorl signals to the modem.
        o LSR Monitor the status of the serial port.
        o MSR Receive status of the modem.
        o DLL Low byte of baud rate divisor.
        o DHH High byte of baud rate divisor.
*/
#define TXR       0    /* Transmit register (WRITE) */
#define RXR       0    /* Receive register  (READ)  */
#define IER       1    /* Interrupt Enable          */
#define IIR       2    /* Interrupt ID              */
#define LCR       3    /* Line control              */
#define MCR       4    /* Modem control             */
#define LSR       5    /* Line Status               */
#define MSR       6    /* Modem Status              */
#define DLL       0    /* Divisor Latch Low         */
#define DLH       1    /* Divisor latch High        */

#define DLAB      0x80      /* */
/*-----------------------------------------------------------------*
  Bit values held in the Line Control Register (LCR).
        bit             meaning
        ---             -------
```

```
0-1          00=5 bits, 01=6 bits, 10=7 bits, 11=8 bits.
2            Stop bits.
3            0=parity off, 1=parity on.
4            0=parity odd, 1=parity even.
5            Sticky parity.
6            Set break.
7            Toggle port addresses.
*-----------------------------------------------------------*/
#define NO_PARITY      0x00
#define EVEN_PARITY    0x18
#define ODD_PARITY     0x08


/*----------------------------------------------------------*
 Bit values held in the Line Status Register (LSR).
        bit          meaning
        ---          -------
        0            Data ready.
        1            Overrun error - Data register overwritten.
        2            Parity error - bad transmission.
        3            Framing error - No stop bit was found.
        4            Break detect - End to transmission requested.
        5            Transmitter holding register is empty.
        6            Transmitter shift register is empty.
        7         Time out - off line.
*-----------------------------------------------------------*/
#define RCVRDY       0x01
#define OVRERR       0x02
#define PRTYERR      0x04
#define FRMERR       0x08
#define BRKERR       0x10
#define XMTRDY       0x20
#define XMTRSR       0x40
#define TIMEOUT            0x80

/*----------------------------------------------------------*
 Bit values held in the Modem Output Control Register (MCR).
        bit     meaning
        ---          -------
        0            Data Terminal Ready. Computer ready to go.
        1            Request To Send. Computer wants to send data.
        2            auxillary output #1.
        3            auxillary output #2.(Note: This bit must be
                     set to allow the communications card to send
                     interrupts to the system)
        4            UART ouput looped back as input.
        5-7          not used.
*-----------------------------------------------------------*/
#define DTR          0x01
#define RTS          0x02
#define MC_INT              0x08


/*----------------------------------------------------------*
 Bit values held in the Modem Input Status Register (MSR).
        bit          meaning
        ---          -------
```

```
        0              delta Clear To Send.
        1              delta Data Set Ready.
        2              delta Ring Indicator.
        3              delta Data Carrier Detect.
        4              Clear To Send.
        5              Data Set Ready.
        6              Ring Indicator.
        7              Data Carrier Detect.
*-------------------------------------------------------------*/
#define CTS         0x10
#define DSR         0x20


/*-------------------------------------------------------------*
  Bit values held in the Interrupt Enable Register (IER).
        bit            meaning
        ---            -------
        0              Interrupt when data received.
        1              Interrupt when transmitter holding reg. empty.
        2              Interrupt when data reception error.
        3              Interrupt when change in modem status register.
        4-7            Not used.
*-------------------------------------------------------------*/
#define RX_INT      0x01


/*-------------------------------------------------------------*
  Bit values held in the Interrupt Identification Register (IIR).
        bit            meaning
        ---            -------
        0              Interrupt pending
        1-2          Interrupt ID code
                       00=Change in modem status register,
                       01=Transmitter holding register empty,
                       10=Data received,
                       11=reception error, or break encountered.
        3-7            Not used.
*-------------------------------------------------------------*/
#define RX_ID       0x04
#define RX_MASK      0x07


/*
   These are the port addresses of the 8259 Programmable Interrupt
   Controller (PIC).
*/
#define IMR         0x21  /* Interrupt Mask Register port */
#define ICR         0x20  /* Interrupt Control Port      */


/*
   An end of interrupt needs to be sent to the Control Port of
   the 8259 when a hardware interrupt ends.
*/
#define EOI         0x20  /* End Of Interrupt */


/*
```

```
   The (IMR) tells the (PIC) to service an interrupt only if it
   is not masked (FALSE).
*/
/*unsigned char IRQ[8] = { ~0x01 , ~0x02 , ~0x04 , ~0x80 ,
                            ~0x10 , ~0x */
#define IRQ3          0xF7  /* COM2 */
#define IRQ4          0xEF  /* COM1 */

int SerSetPortBase ( int , unsigned * ) ;
int SerSetSpeed ( unsigned , long ) ;
int SerSetBitsParityStopBit ( unsigned , int , int , int ) ;
int SerPutChar ( unsigned , unsigned char ) ;
int SerPutString ( unsigned , unsigned char * ) ;
int SerInitBuffer ( unsigned ) ;
int SerGetChar ( unsigned ) ;
int SerTestDSR ( unsigned ) ;
int SerTestCTS ( unsigned ) ;

/*  int flag;
  int  SetSerial();
  int  SetOthers(int Parity, int Bits, int StopBit);
  int  SetSpeed(int Speed);
  int  SetPort(int Port);
  void init_serial(void);
  void comm_off(void);

  void setallport(int Port, int Speed, int Parity, int Bits, int StopBit);
  int  putchport (char);
  void putstrport(char *);
  int  getchport(void);
  void offport();
 */
```

Tablet.H file

```
#define PEN_DOWN                      1
#define PEN_UP                               0
#define PEN_OUTPROX                        99
#define TBL_WACOM_II                  3
#define TBL_DATA_ASCII                1
#define TBL_DATA_BINARY                      0
#define TBL_MODE_STREAM                      3
#define TBL_MODE_SWITCH_STREAM                      2
#define TBL_MODE_SUPRESSED                   0
#define TBL_MODE_POINT                       0
#define TBL_TYPE_ABSOLUTE             0
#define TBL_TYPE_RELATIVE                    1
#define TBL_MILLIMETERS               0
#define TBL_INCHES                    1
#define TBL_ALWAYS_TRANSMIT_YES             1
#define TBL_ALWAYS_TRANSMIT_NO              0
#define TBL_BAUD_19200                       7
#define TBL_BAUD_9600                        6
#define TBL_BAUD_4800                        5
#define TBL_BAUD_2400                        4
#define TBL_BAUD_1200                        3
#define TBL_BAUD_600                         2
#define TBL_BAUD_300                         1
```

```
#define TBL_BAUD_150 0
#define TBL_PARITY_NONE 0
#define TBL_PARITY_ODD 1
#define TBL_PARITY_EVEN 2
#define TBL_STOPBITS_1 0
#define TBL_STOPBITS_2 1
#define TBL_DSR_MONITOR_OFF 0
#define TBL_DSR_MONITOR_ON 1
#define TBL_DATALENGTH_7 0
#define TBL_DATALENGTH_8 1
#define TBL_TRANSFER_RATE_MAX 7
#define TBL_TRANSFER_RATE_100 6
#define TBL_TRANSFER_RATE_67 5
#define TBL_TRANSFER_RATE_50 4
#define TBL_TRANSFER_RATE_20 3
#define TBL_TRANSFER_RATE_10 2
#define TBL_TRANSFER_RATE_5 1
#define TBL_TRANSFER_RATE_1 0
#define TBL_ORIGINLOG_UPPER_LEFT 1
#define TBL_ORIGINLOG_LOWER_LEFT 0
#define TBL_DATA_TERMINATOR_CR_LF 2
#define TBL_DATA_TERMINATOR_LF 1
#define TBL_DATA_TERMINATOR_CR 0


int read_point_tablet_pen ( unsigned , int ,
                            struct point_tablet * , struct point_pen *[8] ) ;
int find_set_parameters_tablet ( int comport , unsigned *portbase ) ;
int init_tablet ( int port , unsigned *portbase , int command_set ,
                  int data_format , int operation_mode , int origin_type ,
                  int unit_mesure , int always_transmit , int speed ,
                  int parity , int stopbit , int dsr_monitor ,
                  int datalength , int transfer_rate , int orig_log ,
                  int data_terminator , int max_x , int max_y ) ;
void close_tablet ( unsigned portbase ) ;
```

I. Reading from device

```
/*      This procedure reads synchronized data from the graphic tablet and accelerometers   /*

int read_point_tablet_pen ( unsigned portbase , int read_pen ,
                            struct point_tablet *tablet ,
                            struct point_pen pen[8] )
{
  int ind_package = 0 , reply , debug[10] , i ;
  unsigned char package[7] = { 0 , 0 , 0 , 0 , 0 , 0 , 0 } ;
  if ( read_pen )
    read_point_pen ( &pen[0] ) ;
  i= 0 ;

/* Waiting for synchro-bit */

  do
  {
    if ( ( reply = SerGetChar ( portbase ) ) < 0 )
        return reply ;
    debug[i++] = reply ;
    if ( ( package[0] = (char) reply ) & SYNCROBIT )
        break ;
  } while ( ind_package++ < 10 ) ;

/* Error - No synchro-bit in 10 bytes */

  if ( ind_package >= 10 )
    return SER_SYNCROBIT ;

/* Read the next 6 bytes from tablet and 6 points from accelerometer */

  for ( ind_package = 1 ; ind_package < 7 ; ind_package++ )
  {
    if ( read_pen )
    {
        read_point_pen ( &pen[ind_package] ) ;
    }
    if ( ( reply = SerGetChar ( portbase ) ) < 0 )
        return reply ;
    package[ind_package] = (char) reply ;
  }

/* Read last point from accelerometer */

  if ( read_pen )
    read_point_pen ( &pen[ind_package] ) ;

/* Calculates the values of the signals for tablet */

  tablet->x = ( package[0] & 0x03 ) << 14 ;
  tablet->x += ( package[1] & 0x7f ) << 7 ;
  tablet->x += ( package[2] & 0x7f ) ;
  if ( package[0] & 0x04 )
    tablet->x = - tablet->x ;
  tablet->y = ( package[3] & 0x03 ) << 14 ;
  tablet->y += ( package[4] & 0x7f ) << 7 ;
  tablet->y += ( package[5] & 0x7f ) ;
```

```
    tablet->p = 0 ;
    if ( ! ( package[0] & 0x40 ) )
      tablet->p = 99 ;
    if ( package[3] & 0x04 )
      tablet->y = - tablet->y ;
    if ( package[6] & 0x20 )
      tablet->p = ( package[6] & 0x1f ) ;
    return 0 ;
}
```

<u>II. Pre-processing</u>

```
/*      Two procedures: Normalization in time and filtering the input signals by smoothing
                                        */

void normal ( int num_old , float arr_old[] , int num_new , float arr_new[] )
{
  double koeff ;
  int ind_old , ind_new ;
  koeff = (double) ( num_old - 1 ) / (float) ( num_new - 1 ) ;
  arr_new[0] = arr_old[0] ;
  for ( ind_new = 1 ; ind_new < num_new - 1 ; ind_new ++ ) {
    ind_old = (int) ( floor ( koeff * ind_new ) ) ;
    arr_new[ind_new] = ( ind_old + 1 - koeff * ind_new ) * arr_old[ind_old] +
                        ( koeff * ind_new - ind_old ) * arr_old[ind_old + 1] ;
    arr_new[ind_new] = arr_new[ind_new] ;
  }
  arr_new[ind_new] = arr_old[num_old-1] ;
}


float smooth1 ( int num , float z[] )
{
  int ind ;
  float temp ;
  float norma ;
  for (ind = 1 , norma = 0 ; ind < num - 1  ; ind++ ) {
    temp = ( z[ind -1]+z[ind]+z[ind+1] ) /3. ;
    norma += abbs ( z[ind] - temp ) ;
    z[ind] = temp ;
  }
  return norma ;
}
```

III. Parameter's extraction

```
/*      Calculation of the parameters of a symbol from the input signals  */

int make_par ( char arg_ch )
{
  struct point {
    unsigned int x    :  12 ;
    unsigned int y    :  12 ;
    unsigned int z    :  12 ;
    unsigned int pen  :   4 ;
  } point , points[500];
  int read_next_symbol ( FILE * , struct point[] ) ;
  char file_name[40] ;
  int len , number_points = 0 ;
  FILE *in_file , *out_file[10] , *out_letter , *out_bin ;
  float  param[6][NUMBER_POINT] , sum_par[6][NUMBER_POINT] ;
  int index = 0 , max_point ;
  int ind , start ;
  int cur_x , cur_y , cur_z , cur_p ;
  float arr_x[MAX_POINT] , arr_y[MAX_POINT] , arr_z[MAX_POINT] , arr_p[MAX_POINT] ;

/* Initialization of the results arrays to zero  */

  for ( ind = 0 ; ind < 6 ; ind++ )
    for ( index = 0 ; index < NUMBER_POINT ; index++ ) {
      param[ind][index] = 0.0 ;
      sum_par[ind][index] = 0.0 ;
    }

/* Identification of the file of data  */

  sprintf ( file_name , "%03d.smb" , (int) arg_ch ) ;
  if ( ( in_file = fopen ( file_name , "rb" ) ) == NULL )
  {
    strcpy (ext_err,file_name);
    return -4 ;
  }
  start = 0 ;

/*  Reading data from file  */

  while ( ( max_point = read_next_symbol ( in_file , points ) ) > 0 ) {
    for ( index = 0 ; index < max_point ; index++ ) {
      arr_x[index] = (float) points[index].x ;
      arr_y[index] = (float) points[index].y ;
      arr_z[index] = (float) points[index].z ;
      arr_p[index] = (float) points[index].pen ;
    }
    arr_p[0] = arr_p[max_point - 1] = 1 ;

    start++ ;
    number_points += max_point ;

/* Calling the procedure make_par_let for calculating parameters 1-6  */

    make_par_let ( arr_x , arr_y , arr_z , arr_p , param , max_point - 1 ) ;
```

```
/* Calculating the average of each parameter */

    for ( ind = 0 ; ind < 6 ; ind++ )
      for ( index = 0 ; index < NUMBER_POINT ; index++ ) {
         sum_par[ind][index] += param[ind][index] ;
      }
  }
  for ( ind = 0 ; ind < 6 ; ind++ )
    for ( index = 0 ; index < NUMBER_POINT ; index++ )
      sum_par[ind][index] /= start ;

  sum_par[0][0] = (float) number_points / start ;
  fclose ( in_file ) ;

  /* write avg in Binary file */
  sprintf ( file_name , "%03d.par" , (int) arg_ch ) ;
  out_letter = fopen ( file_name , "wb+") ;
  for ( index = 0 ; index < 6 ; index++ )
     fwrite ( sum_par[index] , sizeof(float) , NUMBER_POINT , out_letter);

  fclose ( out_letter ) ;

  return  start ;

}

void make_par_let ( float arr_x[] , float arr_y[] , float arr_z[] ,
                    float arr_p[] , float param[6][NUMBER_POINT] , int max_point )
{
  float end_smooth;

  float new_arr_x[500] , new_arr_y[500] , new_arr_z[500] , new_arr_p[500] ;
  int ind , index ;

/* Call for pre-processing */

  normal ( max_point , arr_x , NUMBER_POINT , new_arr_x ) ;
  normal ( max_point , arr_y , NUMBER_POINT , new_arr_y ) ;
  normal ( max_point , arr_z , NUMBER_POINT , new_arr_z ) ;
  normal ( max_point , arr_p , NUMBER_POINT , new_arr_p ) ;
  max_point = NUMBER_POINT ;
  for ( ind = 0 ; ind < max_point ; ind++ ) {
    arr_x[ind] = new_arr_x[ind] ;
    arr_y[ind] = new_arr_y[ind] ;
    arr_z[ind] = new_arr_z[ind] ;
    arr_p[ind] = new_arr_p[ind] ;
  }
 while ( ( end_smooth = smooth1 ( max_point , arr_x ) ) > NUMBER_POINT / 10 ) ;
 while ( ( end_smooth = smooth1 ( max_point , arr_y ) ) > NUMBER_POINT / 10 ) ;
 while ( ( end_smooth = smooth1 ( max_point , arr_z ) ) > NUMBER_POINT / 10 ) ;

/* Initialization of parameters */
  param[0][0] = (float) arr_p[0] ;
  param[1][0] = ( arr_z[0] - arr_z[0] ) ;
  param[2][0] = 0.0 ;
  param[3][0] = 0.0 ;
  param[4][0] = 0.0 ;
  param[5][0] = 0.0 ;
```

```
  param[0][1] = (float) arr_p[1] ;

/* Calculation of parameters */
  param[1][1] = ( arr_z[1] - arr_z[0] ) ;
  elev ( arr_x[2] - arr_x[0] , arr_y[2] - arr_y[0] , arr_z[2] - arr_z[0] ,
           &param[2][1] , &param[3][1] ) ;
  param[4][1] = 0.0 ;
  param[5][1] = 0.0 ;
  for ( index = 2 ; index < max_point - 2 ; index++ ) {
    param[0][index] = (float) arr_p[index] ;
    param[1][index] = ( arr_z[index] - arr_z[0] ) ;
    elev ( arr_x[index + 1] - arr_x[index - 1] , arr_y[index + 1] - arr_y[index - 1] , arr_z[index + 1] -
arr_z[index - 1] ,
           &param[2][index] , &param[3][index] ) ;
    angles ( arr_x[index + 2] - arr_x[index] ,
             arr_y[index + 2] - arr_y[index] ,
             arr_z[index + 2] - arr_z[index] ,
             arr_x[index] - arr_x[index - 2] ,
             arr_y[index] - arr_y[index - 2] ,
             arr_z[index] - arr_z[index - 2] ,
             &param[4][index] , &param[5][index] ) ;
    index = index ;
  }
  param[0][index] = (float) arr_p[index] ;
  param[1][index] = ( arr_z[index] - arr_z[0] ) ;
  elev ( arr_x[index + 1] - arr_x[index - 1] , arr_y[index + 1] - arr_y[index - 1] , arr_z[index + 1] -
arr_z[index - 1] ,
           &param[2][index] , &param[3][index] ) ;
  param[4][index] = 0.0 ;
  param[5][index] = 0.0 ;
  index++ ;

/* Calculation of parameters for last point */
  param[0][index] = (float) arr_p[index] ;
  param[1][index] = ( arr_z[index] - arr_z[0] ) ;
  param[2][index] = 0.0 ;
  param[3][index] = 0.0 ;
  param[4][index] = 0.0 ;
  param[5][index] = 0.0 ;
}


/* Procedure elev calculates the SIN and COS of the angle of elevation */

void elev ( float x , float y , float z , float *cos_ug , float *sin_ug )
{
  float norma ;
  norma = (float) sqrt ( x * x + y * y + z * z ) ;
  if ( norma < .00001 ) {
    *cos_ug = 0.0 ;
    *sin_ug = 0.0 ;
    return ;
  }
  *cos_ug = ( (float) sqrt ( x * x + y * y ) ) / norma ;
  *sin_ug = z / norma ;
  return ;
}
```

```
/* Procedure angles calculates the SIN and COS of the angle β */

void angles ( float x1 , float y1 , float z1 , float x2 , float y2 , float z2 ,
           float *cos_ug , float *sin_ug )
{
  float norma1 , norma2 , x3 , y3 , z3 ;
  norma1 = ( float ) sqrt ( x1 * x1 + y1 * y1 + z1 * z1 ) ;
  norma2 = ( float ) sqrt ( x2 * x2 + y2 * y2 + z2 * z2 ) ;
  if ( norma1 < .0001 || norma2 < .0001 ) {
    *cos_ug = 0.0 ;
    *sin_ug = 0.0 ;
    return ;
  }
  *cos_ug = ( x1 * x2 + y1 * y2 + z1 * z2 ) / norma1 / norma2 ;
  x3 = ( y1 * z2 - z1 * y2 ) ;
  y3 = ( x2 * z1 - x1 * z2 ) ;
  z3 = ( x1 * y2 - x2 * y1 ) ;
  *sin_ug = ( (float) sqrt ( x3 * x3 + y3 * y3 + z3 * z3 ) ) / norma1 / norma2 ;
  return ;
}
```

IV. Training procedures

```
/* Procedure for preliminary teaching */

int first_teach ( void )
{
  FILE *fp ;
  FILE *fpout;
  int i;
  char buf[4] , NdxStr[4] , symbols[256] ;
  int ndx = 0 , max_symb = 0 ;
  int num_sym;
  comment ("converting data files, please wait",0,1);

  if ( ( fp=fopen ( "symbols.dat" , "r" ) ) == NULL )
  {
      strcpy (ext_err,"symbols.dat");
      hide_comment ("converting data files, please wait",0);
      return (-4);
  }
  while ( fscanf ( fp , "%s" , buf ) > 0 )
    symbols[max_symb++] = buf[0] ;
  fclose ( fp ) ;

  fpout=fopen ("text.adp","w");

  for ( ndx = 0 ; ndx < max_symb ; ndx++ ) {
    sprintf ( NdxStr , "%03d" , ndx ) ;
    if ( ( num_sym=make_par ( symbols[ndx] ) ) <= 0 )
    {
       hide_comment ("converting data files, please wait",0);
       return (num_sym);
    }
    else for (i=0;i<num_sym;i++)
                fprintf (fpout,"%c",symbols[ndx]);
  }
  fclose (fpout);
  hide_comment ("converting data files, please wait",0);
  return (0);
}


/* procedure for adaptation of prototypes */

float huge *all_par[100] ;
int first_adap ( void )
{
  float old_rec , new_rec ;
  int count=0 , temp ;
  char *text ;
  char str[80];
  if ( ( temp = read_text ("try.txt", &text ) ) < 0 )
    return ( temp ) ;
  read_param ( ) ;
  new_rec = recogn ( "try.prl" , text , 0 , 0 ) ;
  sprintf (str,"%3f-before adaptation",new_rec);
  comment (str,-1,1);
  do {
```

```
    if (new_rec < 0 ) {
      hide_comment (str,-1);
      while ( all_par[temp] != NULL ) {
          farfree ( all_par[temp++] ) ;
      }
      return ((int) new_rec);
    }
    if ( new_rec  > .995 )
      break ;
    old_rec = new_rec ;
    new_rec = recogn ( "try.prl", text , 1 , 0 ) ;
    if (new_rec <0 ) {
      hide_comment (str,-1);
      while ( all_par[temp] != NULL ) {
          farfree ( all_par[temp++] ) ;
      }
      return ((int) new_rec);
    }
    hide_comment (str,-1);
    sprintf (str,"%3f- in adaptation",new_rec);
    comment (str,-1,1);

    new_rec = recogn ( "try.prl", text , 0 , 0 ) ;

    hide_comment (str,-1);
    sprintf (str,"%3f-after adaption",new_rec);
    comment (str,-1,1);

    if (new_rec < 0 ) {
        hide_comment (str,-1);
        while ( all_par[temp] != NULL ) {
          farfree ( all_par[temp++] ) ;
        }
        return ((int) new_rec);
    }

  } while ( fabs ( old_rec - new_rec ) > .005 & count++ < 9 ) ;
  hide_comment (str,-1);
  farfree ( text ) ;
  while ( all_par[temp] != NULL ) {
    farfree ( all_par[temp++] ) ;
  }
  return 0 ;
}
```

V. Symbol's recognition

```
struct point {
  unsigned int x    :  12 ;
  unsigned int y    :  12 ;
  unsigned int z    :  12 ;
  unsigned int pen  :   4 ;
} ;

struct reply
{
   int   ndx;
   float weight;
};

float recogn ( char *file_pen , char *text ,  int adapt , int words )
{
  float old_rec , new_rec , probs[10][20] ;
  int count=0 ;
  char symbols[256] , buf[4] ;
  unsigned long ttt ;
  int max_symb;
  FILE *in_file , *file_symb , *temp_word ;
  int symb;
  unsigned long start_word , end_word ;
  float  param[6][NUMBER_POINT] ;
  int index = 0 , max_point ;
  struct reply *repl ;
  int temp;
  int Ngood=0;
  int ind , NumSymbols ,ndx;
  struct point symb_pnts [MAX_POINT];
  float arr_x[MAX_POINT] , arr_y[MAX_POINT] , arr_z[MAX_POINT] , arr_p[MAX_POINT] ;
  int map[256];
  int order=0;
  char letters[10][20],dict_wrds[10][20];
  int end_of_word=0;
  int wrdlen;
  float sum[10],maxsum,ndx_maxsum;
  char org_wrd[20],f_word[20];
  int txt_width;
  int i;
  if ( ( file_symb = fopen ( "symbols.dat" , "r" ) ) == NULL ) {
    strcpy (ext_err,"symbols.dat");
    return (-4);
  }

  for (ind=0;ind<256;ind++) map[ind]=-1;
  max_symb = 0 ;
  while ( fscanf ( file_symb , "%s" , buf ) > 0 )
  {
    map [buf[0]]=max_symb;
    symbols[max_symb++] = buf[0] ;
  }
  fclose ( file_symb ) ;
  symbols[max_symb] = 0 ;

  for ( ind = 0 ; ind < 6 ; ind++ )
```

```
    for ( index = 0 ; index < NUMBER_POINT ; index++ ) {
      param[ind][index] = 0.0 ;
    }
  if ( ( in_file = fopen ( file_pen , "rb" ) ) == NULL )
  {
    strcpy (ext_err,file_pen);
    return -4 ;
  }
  index = 0 ;
  NumSymbols = 0 ;
  symb=-1;
        if (adapt)
          repl = make_corr ( param , symbols , symb) ;
        else {
          repl = make_corr ( param , symbols , -1) ;
        }
        if (repl[0].ndx<0)
          return ( repl[0].weight);

        if (repl[0].ndx==symb)
          Ngood++;
        else
          Ngood = Ngood ;
    }
  fclose ( in_file ) ;
  if (NumSymbols==0) return 0;
    else return (Ngood/(float)NumSymbols) ;
}


/* Calculation of the similarity of all the parameters of all the prototypes and the
   symbol to be recognized */

extern float huge *all_par[100] ;

struct reply
{
  int   ndx;
  float weight;
};

static int comm_count = 0 , abs_count = 0 ;
int obj_funct ( float [100][7] , int , int , float [100] , float [7] , int [10] ) ;
float correl_hem ( float [NUMBER_POINT] , float [NUMBER_POINT] , float ) ;
float correl ( float [NUMBER_POINT] , float [NUMBER_POINT] ) ;
struct reply *make_corr ( float cur_par[6][NUMBER_POINT] , char *symbols ,int symb)
{
  FILE *cur_file ;
  int ind_repl , ind_corrct , ind , max_symb , ind_symb , index ;
  struct reply arr_repl[30];
  int arr_ind[10];
  float res[100] , nres[7] , old_max_pnt = cur_par[0][0] , com_wight ;
  float old_max_pnt2 , corr[100][7] , tmp_par[6][NUMBER_POINT] ;
  char buf[8] ;
  int iterat;
  struct reply rt;
  int i,j;
```

```
max_symb = strlen ( symbols ) ;
for ( ind_symb = 0 ; ind_symb < max_symb ; ind_symb++ ) {
  for ( i = 0 ; i < 6 ; i++ )
    for ( j = 0 ; j < NUMBER_POINT ; j++ )
    tmp_par[i][j] = all_par[ind_symb][i*100+j] ;
  if ( tmp_par[0][0] > 0 ) {
    cur_par[0][0] = old_max_pnt ;
    corr[ind_symb][N_PAR-1] = 1.0 * ( 1 -
            min ( fabs ( tmp_par[0][0] - cur_par[0][0] ) / cur_par[0][0] , 1 ) ) ;

    old_max_pnt = cur_par[0][0] ;
    tmp_par[0][0] = 1. ;
    cur_par[0][0] = 1. ;
    corr[ind_symb][0] = correl_hem ( cur_par[0] , tmp_par[0] , .9 ) ;
    for ( ind = 1 ; ind < N_PAR - 1; ind++ ) {
        corr[ind_symb][ind] = correl ( cur_par[ind] , tmp_par[ind] ) ;
    }
  }
  else
    for ( ind = 1 ; ind < N_PAR - 1; ind++ ) {
        corr[ind_symb][ind] = 0.0 ;
    }
}

if (symb<0)
{
   index = obj_funct ( corr , max_symb , N_PAR , res , nres , arr_ind ) ;
   iterat=20;
}
else
{
   sprintf ( buf , "%03d.par" , (int) symbols[symb] ) ;
    for ( i = 0 ; i < 6 ; i++ )
        for ( j = 0 ; j < NUMBER_POINT ; j++ )
        tmp_par[i][j] = all_par[symb][i*100+j] ;
   iterat=0;
   while ( (index=obj_funct (corr,max_symb,N_PAR,res,nres, arr_ind))>0
            && (arr_ind[0]i=symb))
   {

        if (iterat>19) break;
        for (ind=0, ind_corrct=0; ind<N_PAR-1 ; ind++)
           if (corr[symb][ind]<0.95 * nres[ind])
           {
              ind_corrct++;
              for (index=0; index < NUMBER_POINT ; index++)
                   tmp_par[ind][index] = tmp_par [ind][index]*.9
                                         +cur_par[ind][index]*.1;
           }
           if (corr[symb][ind]<0.95 * nres[ind])
           {
              ind_corrct++;
              tmp_par[0][0] = tmp_par[0][0] * .9 + old_max_pnt * .1 ;
           }
           if (!ind_corrct) {
             iterat = 20 ;
             break;
           }
```

```
            iterat++;
            cur_par[0][0]= old_max_pnt;
            corr[symb][N_PAR-1]=1-fabs(tmp_par[0][0]-cur_par[0][0])/ cur_par[0][0];
            old_max_pnt = cur_par[0][0];
            old_max_pnt2= tmp_par[0][0];
            tmp_par[0][0] = 1.;
            cur_par[0][0] = 1.;
            corr[symb][0] = correl_hem ( cur_par[0] , tmp_par[0] , .9 ) ;
            for ( ind = 1 ; ind < N_PAR - 1 ; ind++ ) {
               corr[symb][ind] = correl ( cur_par[ind] , tmp_par[ind] ) ;
            }
           cur_par[0][0] = old_max_pnt ;
           tmp_par[0][0] = old_max_pnt2 ;
    } /* while */
  } /* else */

  if ((iterat<20) && (index>0) && (iterat>0))
  {
    cur_file = fopen ( buf , "w+b" ) ;
    for ( index = 0 ; index < N_PAR -1 ; index++ )
      fwrite ( tmp_par[index] , sizeof ( float ) , NUMBER_POINT , cur_file ) ;
    fclose ( cur_file ) ;
     for ( i = 0 ; i < 6 ; i++ )
        for ( j = 0 ; j < NUMBER_POINT ; j++ )
          all_par[symb][i*100+j] = tmp_par[i][j] ;
  }
  index = min ( index , 9 ) ;
  arr_ind[index]=-1;
  res[arr_ind[index]]=-1;
  for (i=0;i<=index;i++)
  {
    arr_repl[i].ndx=arr_ind[i];
    arr_repl[i].weight=-res[arr_ind[i]];
  }
  return arr_repl ;
}



/* Calculation of correlation between two vectors */

float correl ( float first[NUMBER_POINT] , float second[NUMBER_POINT] )
{
  float sumxy = 0.0 , sumx = 0.0 , sumy = 0.0 ,  sumx2 = 0.0 , sumy2 = 0.0 ;
  int i_d , i_s ;
  for ( i_s = 0 ; i_s < NUMBER_POINT ; i_s++ ) {
      sumxy += first[i_s] * second[i_s] ;
      sumx  += first[i_s] ;
      sumy  += second[i_s] ;
      sumx2 += first[i_s] * first[i_s] ;
      sumy2 += second[i_s] * second[i_s] ;
    }
    if ( ( sumx2 - sumx * sumx / NUMBER_POINT ) < 0 ||
          ( sumy2 - sumy * sumy / NUMBER_POINT ) < 0 )
      return 0 ;
    if ( ( sumxy = ( sumxy - sumx * sumy / NUMBER_POINT ) /
```

```
          sqrt ( sumx2 - sumx * sumx / NUMBER_POINT ) /
          sqrt ( sumy2 - sumy * sumy / NUMBER_POINT ) ) < .5 )
      return 0 ;
    return sumxy ;
}


/* Similarity function for the parameter of pen up/down */

float correl_hem ( float par1[NUMBER_POINT] , float par2[NUMBER_POINT] , float border )
{
  int index ;
  float result = 0.0 ;
  for ( index = 1 ; index < NUMBER_POINT ; index++ )
    result += fabs ( par1[index] - par2[index] ) ;
  result /= NUMBER_POINT ;
  result = 1 - result ;
  if ( result < border )
    return 0 ;
  return result ;
}

/* Selection of the list of symbols that are likely to be the symbol to be recognized */

int obj_funct ( float arr[100][7] , int n_symb , int n_par ,
                float res[100] , float nres[7] , int arrindex[30] )
{
  int ind_s , ind_p , ind_arr = 0 ;
  float max_res = 0.0 , cur_res , abs_res = 0.0 ;
  int result = -1 ;
  for ( ind_s = 0 ; ind_s < n_symb ; ind_s++ ) {
    for ( ind_p = 0 , cur_res = 0.0 ; ind_p < n_par ; ind_p++ )
      cur_res += arr[ind_s][ind_p] ;
    res[ind_s] = cur_res ;
    if ( cur_res > max_res ) {
      result = ind_s ;
      max_res = cur_res ;
    }
  }
  abs_res = max_res * .85 ;
  do {
    arrindex[ind_arr++] = result ;
    res[result] = - res[result] ;
    for ( ind_s = 0 , max_res = 0.0 ; ind_s < n_symb ; ind_s++ )
          if ( res[ind_s] > max_res ) {
            result = ind_s ;
            max_res = res[ind_s] ;
          }
  } while ( max_res > abs_res && ind_arr < 30 ) ;
  for ( ind_p = 0 ; ind_p < n_par ; ind_p++ )
    for ( ind_s = 0 , nres[ind_p] = -5  ; ind_s < n_symb ; ind_s++ )
      nres[ind_p] = max ( arr[ind_s][ind_p] , nres[ind_p] ) ;
  return ind_arr ;
}
```

C L A I M S

1. Information input apparatus comprising:

body supported apparatus for sensing voluntary body motions and providing an output indication thereof;

a symbol output interpreter operative to utilize said output indication for providing symbol outputs; and

a motion output interpreter operative to utilize said output indication for providing motion control outputs.

2. Information input apparatus according to claim 1 and wherein said output indication represents features of body motion including features which are characteristic of the individual.

3. Information input apparatus according to either of claims 1 and 2 and also comprising a mode selector operative to cause a selected one of the symbol output interpreter and the motion output interpreter to function.

4. Information input apparatus according to any of the preceding claims and wherein said body supported apparatus is a hand held device.

5. Information input apparatus according to any of the preceding claims and wherein said body supported apparatus is a generally pen-shaped device.

6. Information input apparatus according to claim 5 and wherein said generally pen-shaped device is operative to provide a visible writing function.

7. Information input apparatus according to any of the preceding claims and also comprising an object whose motion is controlled by said motion control outputs.

8. Information input apparatus according to claim 7 and wherein said object is a graphic object displayed on a display.

9. Information input apparatus according to claim 7 and wherein said object is a physical object.

10. Information input apparatus according to any of the preceding claims and wherein said symbol outputs represent alphanumeric symbols.

11. Information input apparatus according to any of the preceding claims and wherein said symbol outputs represent a sensory quality.

12. Information input apparatus according to claim 7 and also comprising a computer, having a location input and a symbol input, and a display operated by said computer and wherein said symbol outputs represent information to be displayed on said display and said motion outputs are supplied to said location input and are employed by the computer to govern the location of said information on said display.

13. Information input apparatus according to claim 7 or claim 12 and wherein said symbol outputs include function commands.

14. A method by which a manipulable device provides an output indication representing its own angular motion, the method comprising:

recording actual acceleration data from a

plurality of accelerometers mounted in the manipulable device;

generating predicted acceleration data on the basis of hypothetical angular motion information;

comparing the predicted acceleration data to the actual acceleration data;

computing improved hypothetical angular motion information;

while the predicted acceleration data differs significantly from the actual acceleration data, repeating the generating, comparing and computing steps; and

providing an output indication of the improved hypothetical angular motion information.

15. A method according to claim 14 wherein the angular motion information includes angular displacement information, angular velocity information and angular acceleration information.

16. A method according to claim 14 or claim 15 and also comprising computing linear motion information from the improved hypothetical angular motion information and from the actual acceleration data.

17. A method according to any of claims 14 - 16 wherein recording comprises recording from at least four accelerometers mounted in the manipulable device, wherein the accelerometers each have a center of mass and wherein the centers of mass do not lie within a single plane.

18. A method according to any of the preceding claims 14 - 17 and also comprising receiving the output indication of the improved hypothetical angular motion information and manipulating an object in accordance therewith.

19. An accelerometer array mounted in a manipulable device and comprising:

at least four accelerometers each having a center of mass, wherein the centers of mass do not lie within a single plane; and

a manipulable device motion computer receiving input from the accelerometers and generating an output signal indicative of the motion of the manipulable device.

20. Apparatus according to claim 19 wherein the manipulable device motion computer is operative to perform the following steps:

recording actual acceleration data from the accelerometers;

generating predicted acceleration data on the basis of hypothetical angular motion information;

comparing the predicted acceleration data to the actual acceleration data;

computing improved hypothetical angular motion information;

while the predicted acceleration data differs significantly from the actual acceleration data, repeating the generating, comparing and computing steps; and

providing an output indication of the improved hypothetical angular motion information.

21. Apparatus according to any of claims 19 - 20 and also comprising an object manipulator receiving the output signal indicative of the motion of the manipulable device and manipulating an object in accordance therewith.

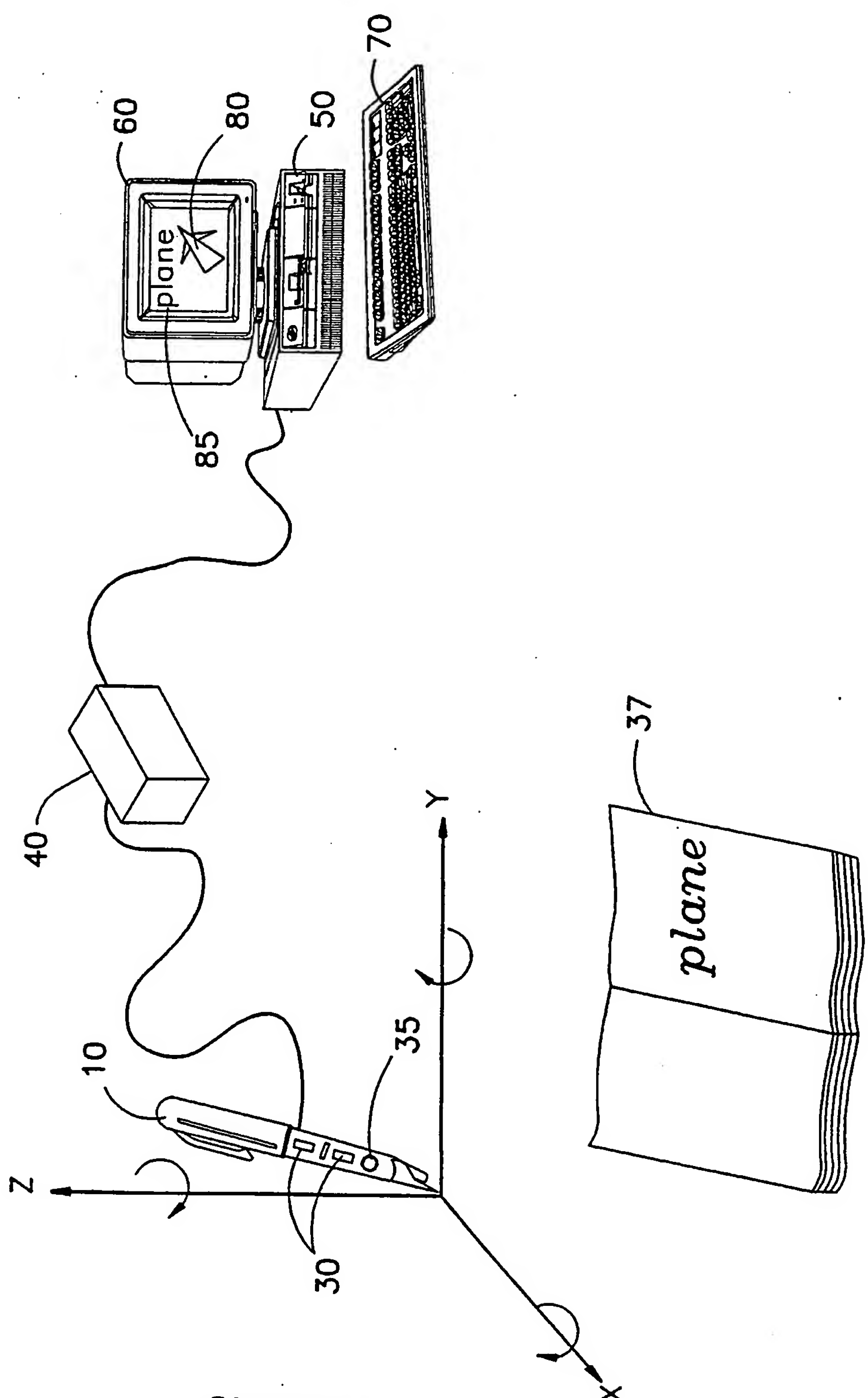
22. An information input method comprising:

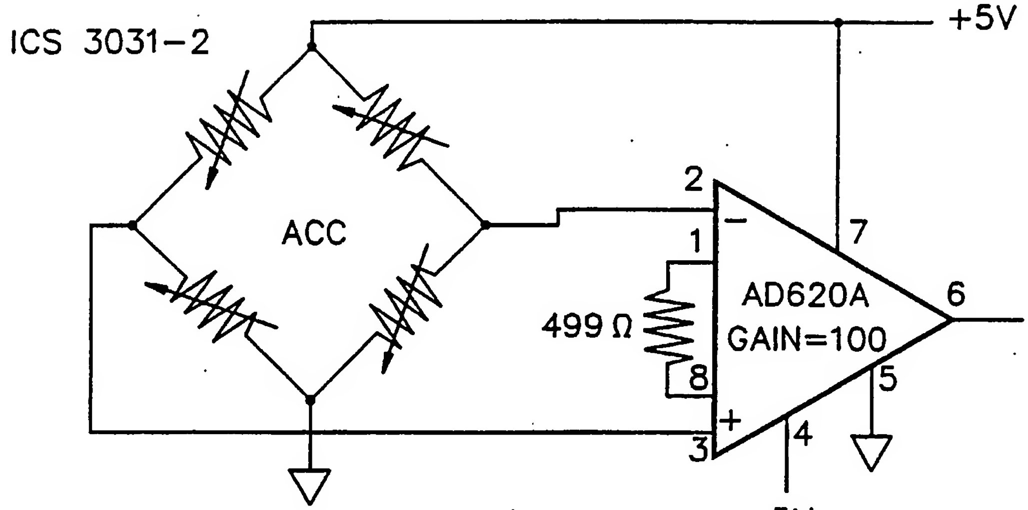
sensing voluntary body motions and providing an output indication thereof;

utilizing said output indication for providing symbol outputs; and

utilizing said output indication for providing motion control outputs.

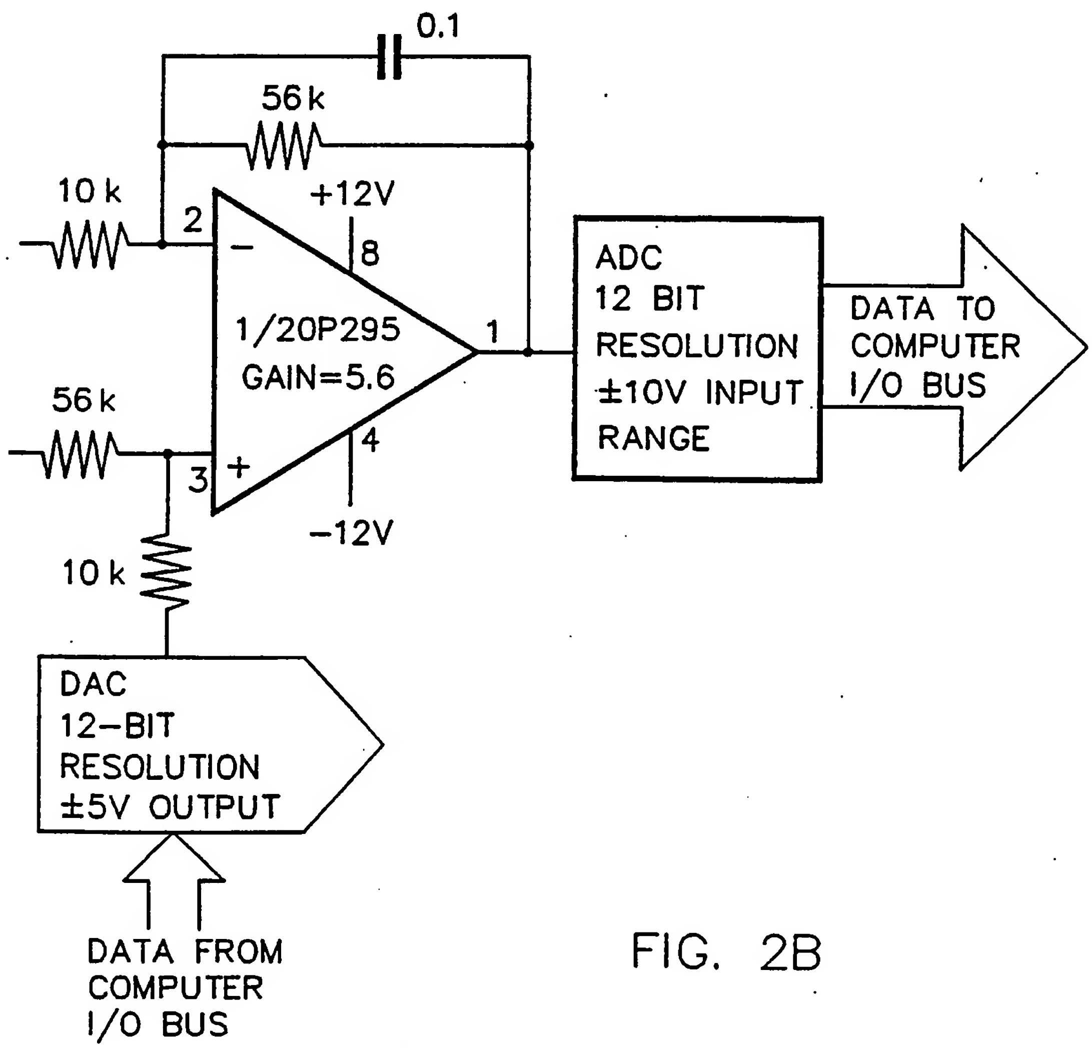
FIG. 1





ICS 3031-2
+5V
ACC
2
−
7
1
AD620A
GAIN=100
6
499 Ω
8
5
+
4
3
−5V

FIG. 2A



0.1
56 k
10 k
+12V
2
−
8
1/2OP295
GAIN=5.6
1
56 k
4
3
+
−12V
10 k
ADC
12 BIT
RESOLUTION
±10V INPUT
RANGE
DATA TO
COMPUTER
I/O BUS
DAC
12-BIT
RESOLUTION
±5V OUTPUT
DATA FROM
COMPUTER
I/O BUS

FIG. 2B

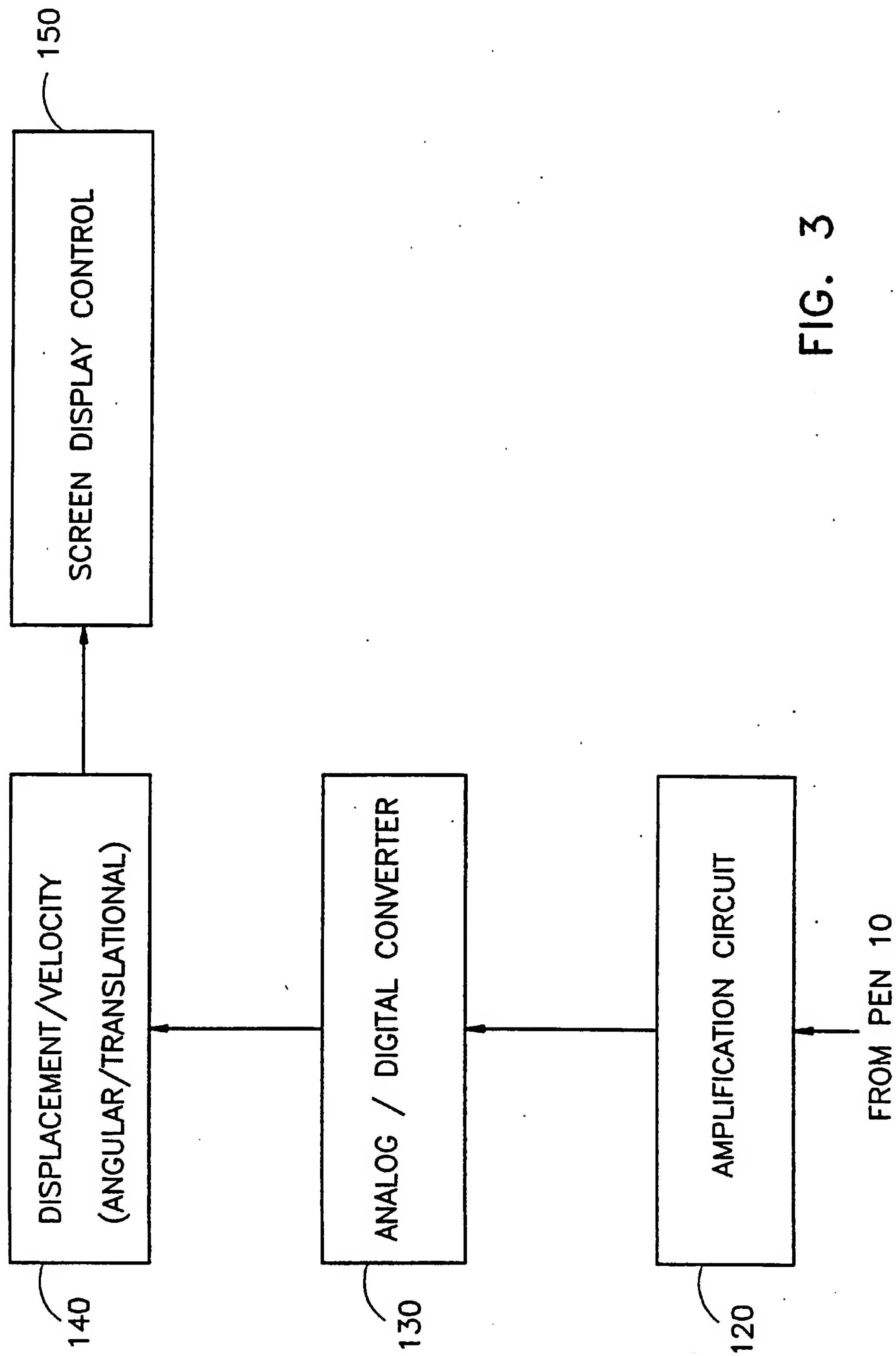

150
SCREEN DISPLAY CONTROL
DISPLACEMENT/VELOCITY
(ANGULAR/TRANSLATIONAL)
140
ANALOG / DIGITAL CONVERTER
130
AMPLIFICATION CIRCUIT
120
FROM PEN 10

FIG. 3

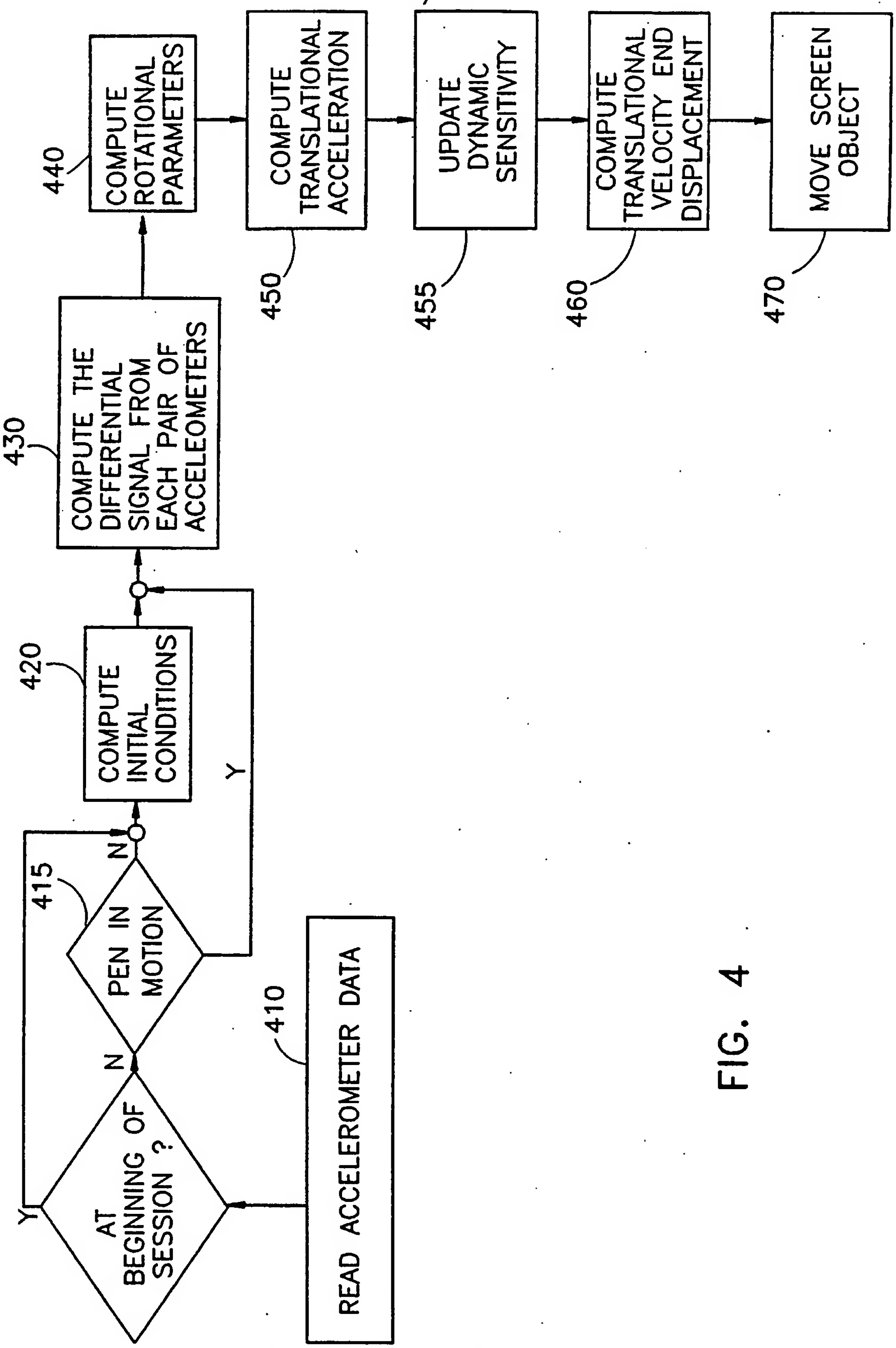

READ ACCELEROMETER DATA
410
AT BEGINNING OF SESSION ?
Y
N
PEN IN MOTION
415
N
Y
COMPUTE INITIAL CONDITIONS
420
COMPUTE THE DIFFERENTIAL SIGNAL FROM EACH PAIR OF ACCELEOMETERS
430
COMPUTE ROTATIONAL PARAMETERS
440
COMPUTE TRANSLATIONAL ACCELERATION
450
UPDATE DYNAMIC SENSITIVITY
455
COMPUTE TRANSLATIONAL VELOCITY END DISPLACEMENT
460
MOVE SCREEN OBJECT
470

FIG. 4

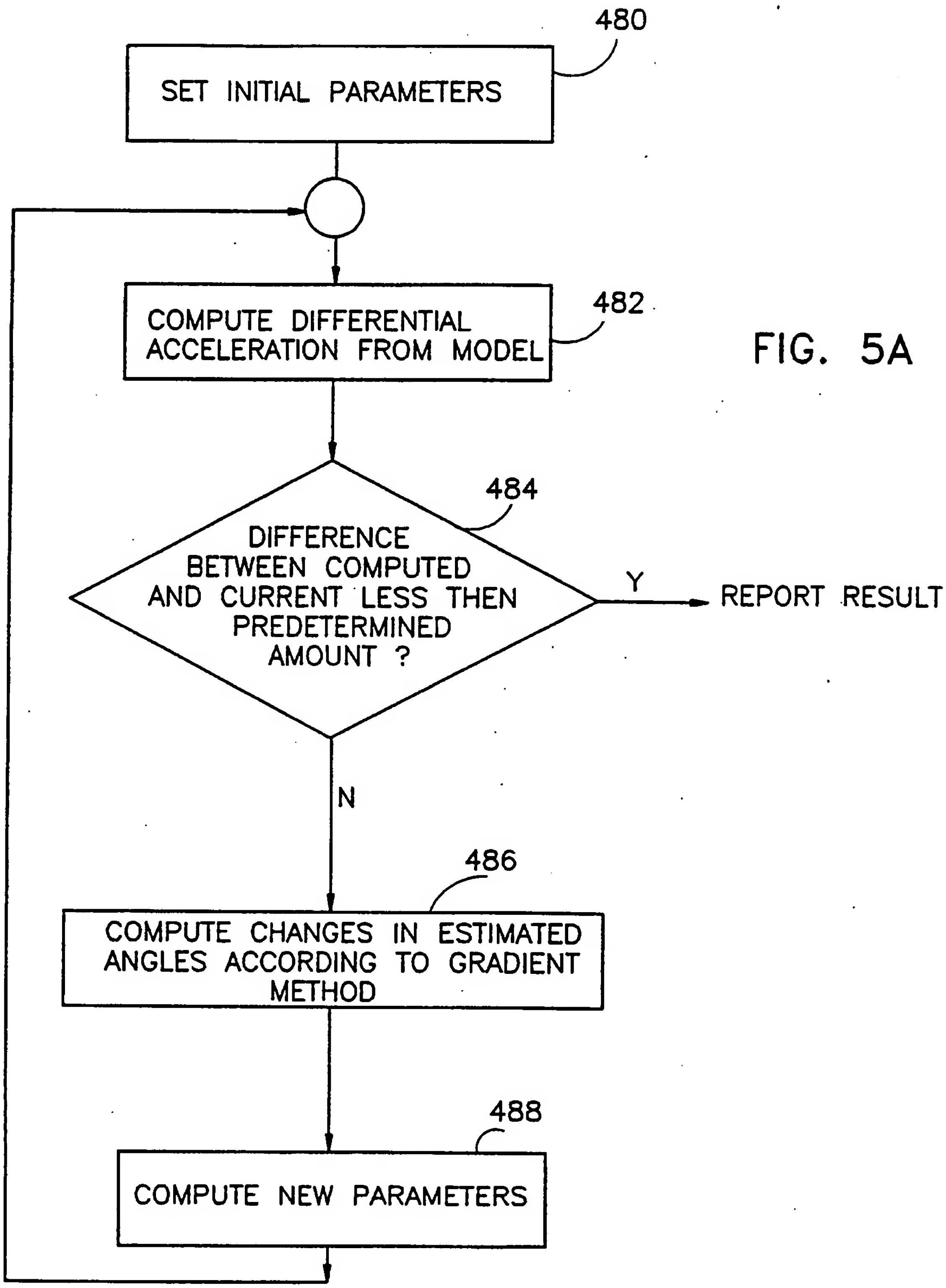

480
SET INITIAL PARAMETERS
482
COMPUTE DIFFERENTIAL ACCELERATION FROM MODEL
484
DIFFERENCE BETWEEN COMPUTED AND CURRENT LESS THEN PREDETERMINED AMOUNT ?
Y
REPORT RESULT
N
486
COMPUTE CHANGES IN ESTIMATED ANGLES ACCORDING TO GRADIENT METHOD
488
COMPUTE NEW PARAMETERS

FIG. 5A

EQUATION 490

$$\frac{d^2R}{dt^2} = \left[\frac{\partial A}{\partial \alpha}\cdot\frac{d^2\alpha}{dt^2} + \frac{\partial A}{\partial \beta}\cdot\frac{d^2\beta}{dt^2}\cdot\frac{\partial A}{\partial \gamma} + \frac{d^2\gamma}{dt^2} + \right.$$

$$+\frac{\partial^2 A}{\partial \alpha^2}\cdot\left(\frac{d\alpha}{dt}\right)^2 + \frac{\partial^2 A}{\partial \beta^2}\cdot\left(\frac{d\beta}{dt}\right)^2 + \frac{\partial^2 A}{\partial \gamma^2}\cdot\left(\frac{d\gamma}{dt}\right)^2 +$$

$$\left. +2\frac{\partial^2 A}{\partial \alpha \partial \beta}\cdot\frac{d\alpha}{dt}\frac{d\beta}{dt} + 2\frac{\partial^2 A}{\partial \alpha \partial \gamma}\cdot\frac{d\alpha}{dt}\frac{d\gamma}{dt} + 2\frac{\partial^2 A}{\partial \beta \partial \gamma}\cdot\frac{d\beta}{dt}\frac{d\gamma}{dt}\right] * r$$

EQUATION 492

$$K(\varphi) = A \cdot K_0$$

EQUATION 494

$$U_{est} = K_0^T \cdot A^T \cdot \frac{d^2R}{dt^2}$$

EQUATION 496

$$\varphi(t) = \varphi_0' + \varphi_0 t + \frac{\varphi_0''}{2} t^2 + pt^3$$

$$\varphi'(t) = \varphi_0' + \varphi_0'' t + 3pt^2$$

$$\varphi''(t) = \varphi_0'' + 6pt$$

FIG. 5B

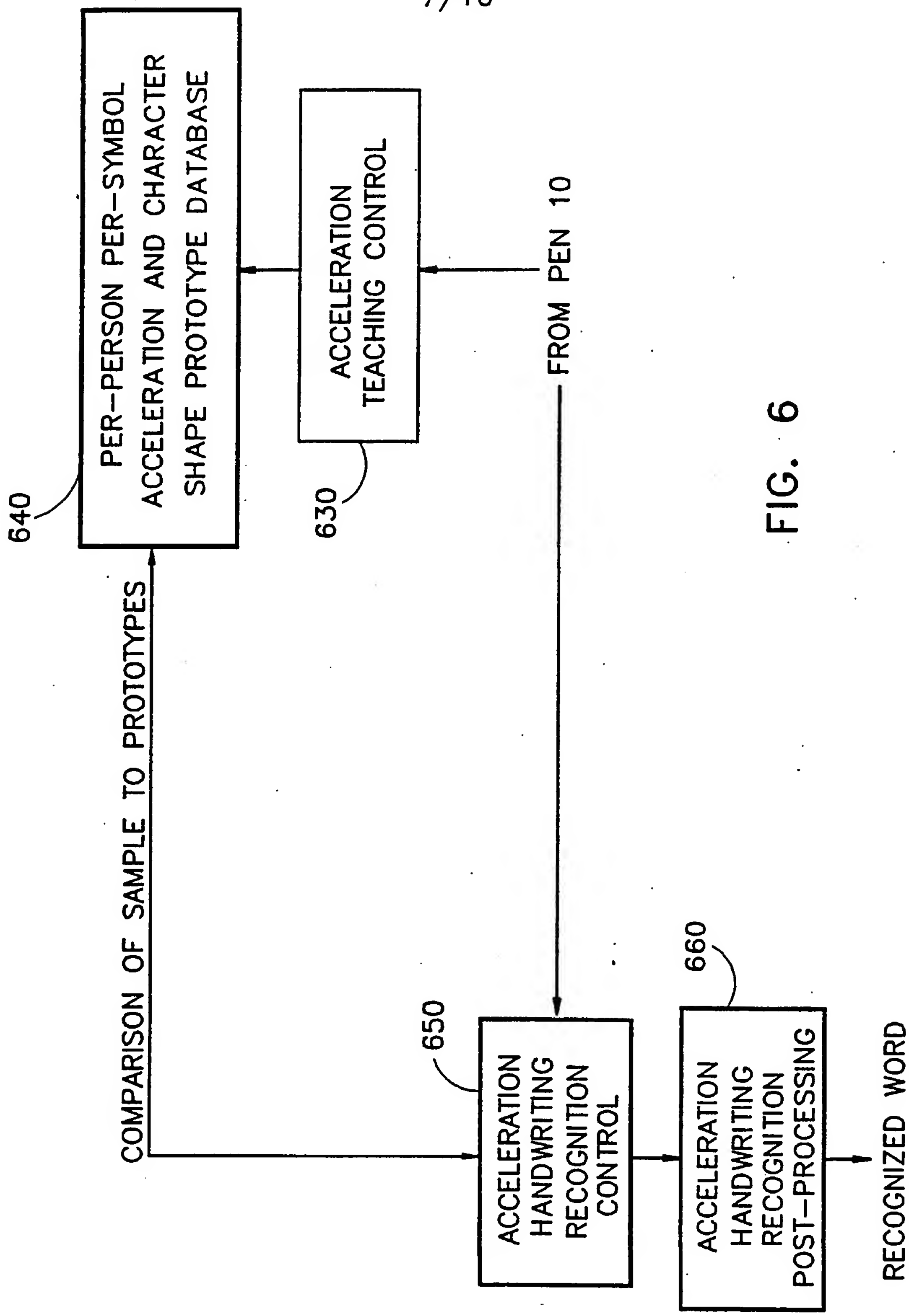

PER–PERSON PER–SYMBOL ACCELERATION AND CHARACTER SHAPE PROTOTYPE DATABASE
640
ACCELERATION TEACHING CONTROL
630
FROM PEN 10
COMPARISON OF SAMPLE TO PROTOTYPES
650
ACCELERATION HANDWRITING RECOGNITION CONTROL
660
ACCELERATION HANDWRITING RECOGNITION POST–PROCESSING
RECOGNIZED WORD

FIG. 6

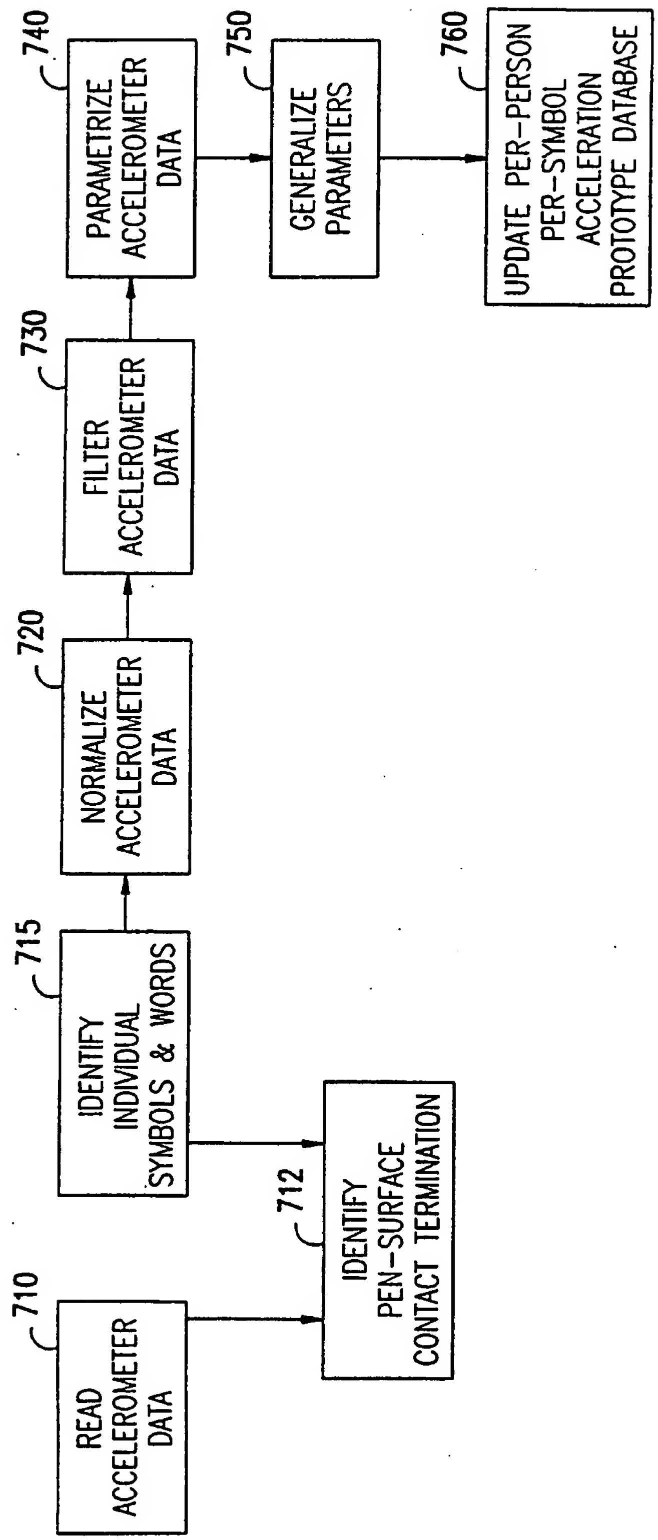

710
READ ACCELEROMETER DATA
712
IDENTIFY PEN-SURFACE CONTACT TERMINATION
715
IDENTIFY INDIVIDUAL SYMBOLS & WORDS
720
NORMALIZE ACCELEROMETER DATA
730
FILTER ACCELEROMETER DATA
740
PARAMETRIZE ACCELEROMETER DATA
750
GENERALIZE PARAMETERS
760
UPDATE PER-PERSON PER-SYMBOL ACCELERATION PROTOTYPE DATABASE

FIG. 7A

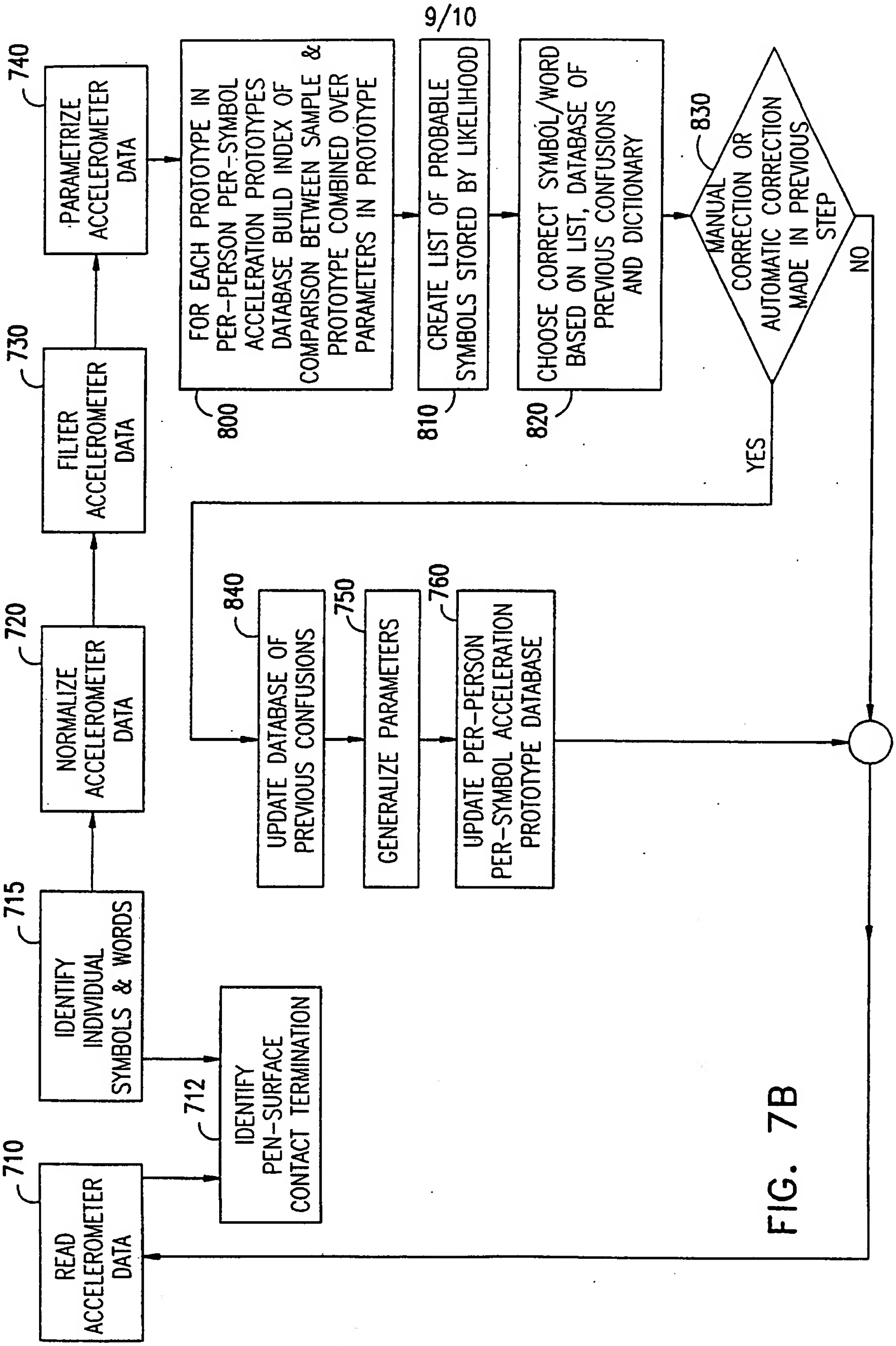


FIG. 7B

SUBSTITUTE SHEET (RULE 26)

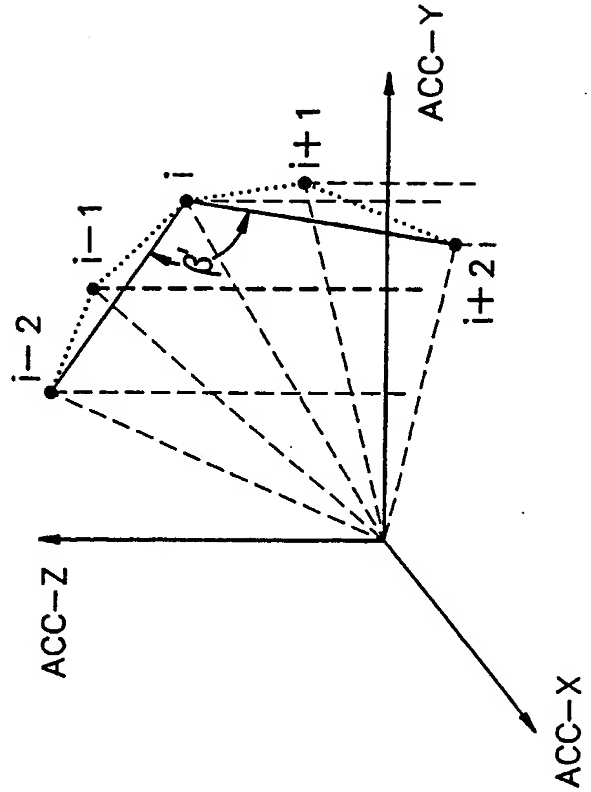


FIG. 8B

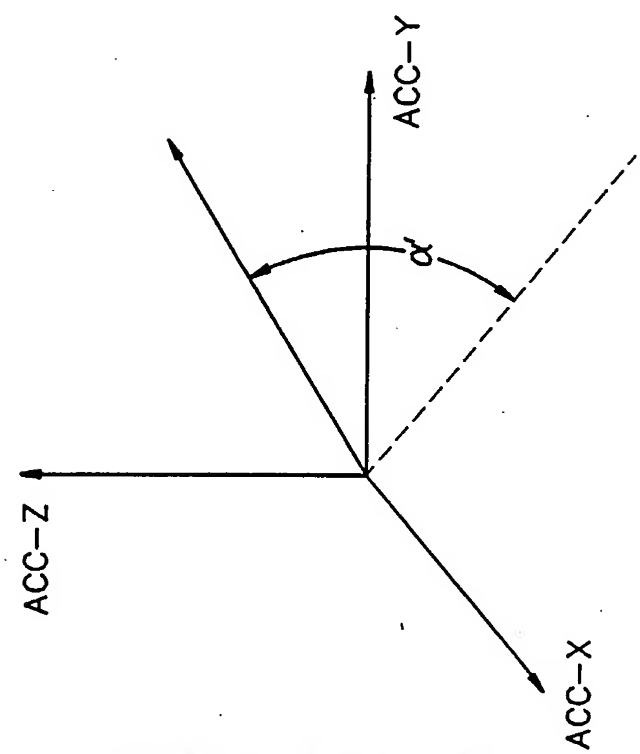


FIG. 8A

SUBSTITUTE SHEET (RULE 26)